The Ecology and Management of Forest Range in British Columbia:

A Review and Analysis

Land Management Report NUMBER 19

ISSN 0702-9861

November 1984

BC
Ministry of Forests

86-04534/

The Ecology and Management of Forest Range in British Columbia: A Review and Analysis

by

L. O. Nordstrom

Ecological Consultant
RR #1, S-152, C. 25
Bowser, B.C.
V0R 1G0

British Columbia
Ministry of Forests
Research Branch
1450 Government Street
Victoria, B.C.
V8W 3E7

Province of British Columbia
Ministry of Forests

Canadian Cataloguing in Publication Data

Nordstom, L.
The ecology and management of forest range in British Columbia

(Land management report, ISSN 0702-9861; no. 19)

Bibliography: p.
ISBN 0-7718-8455-9

1. Forest ecology — British Columbia. 2. Forest management — British Columbia. 3. Range ecology — British Columbia. 4. Range management — British Columbia. 5. Grazing — British Columbia. I. British Columbia. Ministry of Forests. Forestry Division. Research Branch. II. Title. III. Series.

SD146.B7N67 1984 333.75'09711 C84-092283-3

© 1984 Province of British Columbia

Published by the
Information Services Branch
Ministry of Forests
Parliament Buildings
Victoria, B.C.
V8W 3E7

Copies of this and other Ministry of Forests titles are available at a cost-recovery price from the Queen's Printer Publications, Parliament Buildings, Victoria, B.C. V8V 4R6.

EXECUTIVE SUMMARY

The compatibility of forestry and grazing interests on Crown forestland in British Columbia has been questioned on ecological grounds. Most frequently, the controversy has revolved around the apparent inimical effects of cattle and seeded forage grasses on the survival and growth of coniferous regeneration. Resolution of these and related issues depends on conclusive experimental research to establish a sound ecological data base.

This review has endeavoured to synthesize the scientific literature on forest grazing throughout North America, and to assess the applicability of results from these geographically widespread studies to the situation in British Columbia. As well, specific research needs have been identified and are summarized as follows:

- Further varietal trials to identify well-adapted species and strains of domestic grass and legume forages for seeding clearcuts and burns, particularly in the BWBS, ESSF, ICH, MS and SBS biogeoclimatic zones.
- Research to evaluate the contribution of seeded legumes to total soil nitrogen on clearcuts and burns.
- Systematic, quantitative follow-up of forage seedings, with emphasis on germination, establishment, mortality, distribution and population dynamics of the sown species over time.
- Research to determine the degree of mineral soil exposure required for satisfactory and compatible establishment of coniferous regeneration and seeded forages on clearcuts.
- Identification of grass/legume species compatible with the regeneration requirements of such conifers as Engelmann and white spruce, Douglas-fir and subalpine fir.
- Determination of grass/legume seeding rates amenable to joint production of trees and domestic forage on clearcuts.
- Investigation of long-term relationships between tree growth and herbage production with respect to time of grass/legume sowing on different range sites.
- Verification of the applicability of zonal or subzonal seed mixes based on B.C. Ministry of Forests ecological classification guidelines.
- Research on the timing and rate of fertilizer application to establish trees and seeded forage on clearcuts.
- Research on the role of allelopathy in tree/forage interactions.
- Comparative analysis of herbage/timber relationships for such conifers as lodgepole pine, Engelmann spruce, white spruce, Douglas-fir and subalpine fir, with particular reference to the influence of canopy closure on the productivity and longevity of seeded forages.
- Comparative analysis of the long-term effects of competition from seeded forage versus native vegetation on conifer survival and growth.
- Assessment of the potential silvicultural benefits derived from competition between seeded forages and tree seedlings, with specific reference to thinning dense stands of natural regeneration.
- Research on the long-term effects of cattle grazing on forage productivity and species composition on clearcuts.
- Long-term research quantifying the relative importance of soils, climate, plant competition, overstory effects, animal grazing and management factors in reducing seeded and native forage yields, and altering species composition over time.
- Development of range condition guidelines for seeded clearcuts.
- Long-term comparative analysis of conifer recovery from and resiliency to trampling/browsing damage by cattle, with specific reference to lodgepole pine, Engelmann spruce, white spruce, Douglas-fir and subalpine fir.
- Quantification of the proportion of damage actually caused by cattle to tree seedlings, as opposed to other sources such as wildlife or poor planting procedures.
- Assessment of the potential silvicultural benefits derived from cattle trampling which acts to thin dense natural tree regeneration, and cropping which tends to reduce competition between grass and trees.
- Research on the relationships between tree thinning and forage production, with special reference to:
  - (i) forage species yield, quality and composition,
  - (ii) differences among conifer species and biogeoclimatic zones,
  - (iii) the growth "release" of remaining conifers as affected by increased development of herbs and shrubs.
- Collection of baseline data on the physical conditions of fuels, weather and topography for prediction of fire intensity, duration and behaviour on forest range.
- Research on the effects of fire on soils and plants, particularly with respect to soil fertility and plant productivity.
- Investigation of post-burn interactions between fire and grazing on vegetation.

- Assessment of seasonal and annual forage production, forage quality and livestock diets on late successional and climax forest ranges.
- Development of range condition guidelines for late successional and climax forest ranges, including identification of increaser, decreaser and invader species.
- Determination of criteria for appraising range readiness on late successional and climax forest range.
- Determination of the relationships between livestock distribution and habitat use on different forest range sites.
- Behavioural studies of social interactions within and between different cattle grazing groups, with respect to improving livestock distribution and overall utilization on a given forest range unit.

ACKNOWLEDGEMENTS

A number of individuals and government agencies have participated in this project. Brian M. Wikeem, Manager for Range Research, B.C. Ministry of Forests, initiated the study and gave valuable editorial assistance and supervision throughout its duration. Financial support was generously provided by the Research and Range Management Branches of the B.C. Ministry of Forests. The Director and staff of the Agriculture Canada Range Research Station, Kamloops, B.C., are thanked for allowing unrestricted use of their library and xeroxing facilities. Dr. M.D. Pitt, Department of Plant Science, University of British Columbia, provided funding for a computer search of the literature.

The following B.C. Ministry of Forests personnel undertook the task of reviewing preliminary drafts of the manuscript and offered constructive comments:

D. Brooke, Range Planning Coordinator, Kamloops Forest Region
B. Clark, Research Forester, Kamloops Forest Region
E. Jenson, Range Administration Coordinator, Victoria
G. Leroux, Range Coordinator, Cariboo Forest Region
T. Lester, Range Resource Coordinator, Victoria
W. McLachlan, Director, Range Management Branch, Victoria
R. Newman, Range Consultant, Research Branch, Kamloops
R. Tucker, Range Resource Coordinator, Kamloops Forest Region

Special thanks are extended to Diane Coffey for assistance in preparing the manuscript, as well as to Paul Nystedt, Research Branch, and to Peter Vander-Velden, Kamloops Forest Region Headquarters, for drawing Figures 1 and 2, respectively. Figures 3–5 are reproduced courtesy of the U.S.D.A. Forest Service.

ERRATA

Nordstrom, L.O. 1984. The ecology and management of forest range in British Columbia: A review and analysis. B.C. Min. of For. Land Management Report No. 19.

Page No.	Line	Appears as	Should be
35	9	glyphosphate	glyphosate
45	6 from bottom	(1976	1976
50	12	et al.	et al.
65	36	ad	and
66	3	over	cover
66	20	(1966c)	1966c)
82	17 from bottom	Brit	Brit.
88	19	populas	populus
89	24	such	such as
84	29	alskie	alsike
ix	Table 7	close bracket	')'

TABLE OF CONTENTS

1 **Introduction** 1

2 **Characteristics of Forest Range Ecosystems in British Columbia** 3

3 **Tree/Forage/Livestock Interactions in Harvested Forest Ecosystems** 7

- 3.1 Establishment of Post-Harvest Forest Communities 7
  - 3.1.1 Trees 7
    - 3.1.1.1 Selection of Species 7
      - 3.1.1.1.1 Distribution of Commercial Species 7
      - 3.1.1.1.2 Regeneration and Silvics 9
    - 3.1.1.2 Site Preparation 11
      - 3.1.1.2.1 Scarification 12
      - 3.1.1.2.2 Prescribed Burning 13
  - 3.1.2 Forages 14
    - 3.1.2.1 Selection of Species 14
      - 3.1.2.1.1 Grasses 15
      - 3.1.2.1.2 Legumes 19
      - 3.1.2.1.3 Forage Mixes 22
    - 3.1.2.2 Site Preparation 24
      - 3.1.2.2.1 Scarification 24
      - 3.1.2.2.2 Prescribed Burning 26
      - 3.1.2.2.3 Fertilization 27
    - 3.1.2.3 Seeding Forage Mixes 28
      - 3.1.2.3.1 Time of Seeding 28
      - 3.1.2.3.2 Rate of Seeding 29
  - 3.1.3 Summary and Discussion 31
- 3.2 Synecology of Post-Harvest Forest Communities 33
  - 3.2.1 Tree/Forage Interactions 33
    - 3.2.1.1 Competition for Soil Moisture 33
    - 3.2.1.2 Options for Reducing Competition 34
    - 3.2.1.3 Silvicultural Benefits from Competition 36
    - 3.2.1.4 Allelopathic Interactions 37
  - 3.2.2 Interspecific and Temporal Dynamics of Seeded Forages 37
    - 3.2.2.1 General Trends 37
    - 3.2.2.2 Species Population Trends 41
  - 3.2.3 Successional Development of Native Vegetation 42
  - 3.2.4 Summary and Discussion 46
- 3.3 Livestock Grazing in Post-Harvest Forest Communities 47
  - 3.3.1 Range Management in Clearcuts 48
    - 3.3.1.1 Forage Production 48
    - 3.3.1.2 Cattle Production 49
    - 3.3.1.3 Forage/Livestock Interactions 50
      - 3.3.1.3.1 Cattle Diets and Forage Utilization 51
      - 3.3.1.3.2 Impact of Grazing on the Plant Community 52
    - 3.3.1.4 Cattle Management to Improve Utilization 53
  - 3.3.2 Tree/Livestock Interactions 54
    - 3.3.2.1 Characteristics and Effects of Animal Damage 54
    - 3.3.2.2 Silvicultural Benefits from Cattle Grazing 55
    - 3.3.2.3 Cattle Management to Control Damage 56
  - 3.3.3 Summary and Discussion 56

4 Tree/Forage/Livestock Interactions in Late Successional and Climax Forest Ecosystems 58
4.1 Forage Production in Stratified Forest Communities 58
4.1.1 Tree/Forage Interactions 58
4.1.2 Timber Management and Forage Production 59
4.1.2.1 Intermediate Cuttings 60
4.1.2.2 Prescribed Burning 61
4.1.3 Summary and Discussion 63
4.2 Range Management in Stratified Forest Communities 64
4.2.1 Forage/Livestock Interactions 65
4.2.1.1 Cattle Diets and Grazing Patterns 65
4.2.1.2 Impact of Grazing on the Plant Community 66
4.2.2 Cattle Production 67
4.2.3 Summary and Discussion 69

5 Economic Aspects of Tree/Forage/Livestock Interactions 70

6 Conclusions 72

7 Literature Cited 73

APPENDICES

1. Common and Scientific Names of Recognized Commercial Tree Species of British Columbia 85
2. Common and Botanical Names of Plant Species Cited 86
3. Grass-Legume Mixes Recommended for Use on Forest Range in Southern British Columbia 89

TABLES

1. Range types on Crown land available for grazing in British Columbia ('000 ha) (B.C. Min. For. 1980) 3
2. Biogeoclimatic zones and their utilization for domestic grazing in each of the Ministry of Forests administrative regions (Wikeem 1983) 4
3. Distribution of AUMs allocated on Crown range for all livestock (cattle, horses, sheep) by Forest Region 1969–1980 4
4. Hectares of clearcut and seeded forest land in British Columbia 1982, by Forest Region (B.C. Min. For. 1982) 6
5. Tree species groups recognized by the British Columbia Ministry of Forests (B.C. Min. For. 1980; Mitchell and Green 1981) 8
6. Timber harvest ('000 cubic metres) and percentage of total productive forest area (in parentheses) by species group and Forest Region in interior British Columbia, 1980 (B.C. Min. For. 1980; 1981) 9
7. Tree species occurrence by biogeoclimatic zone on forest range in British Columbia (Mitchell and Green 1981; Pojar et al. 1982; Utzig et al. 1983 11
8. Abbreviated silvics of common commercial tree species on forest range in British Columbia 12
9. Site preparation by scarification for natural regeneration and planting on Crown land, 1981–1982, by Forest Region (B.C. Min. For. 1982) 13
10. Site preparation by burning for natural regeneration and planting on Crown land, 1981–1982, by Forest Region (B.C.. Min. For. 1982) 14
11. Grass taxa seeded on burned/logged forest in the Pacific Northwest for erosion control and forage production 16
12. Agronomic characteristics of forage grasses commonly seeded on forest range in the Pacific Northwest 17
13. Legume species seeded on burned/logged forest in the Pacific Northwest for erosion control, soil fertility and forage production 19
14. Characteristics of forage legumes commonly seeded on forest range in the Pacific Northwest 20
15. Biogeoclimatic zones and subzones in southern British Columbia for which recommended grass/legume mixes have been formulated 22
16. Yields of timothy, and a timothy/clover mix on burned mixed conifer forestland in Idaho (Christ 1934) 23
17. Grass/legume versus grass yields (kg/ha) at the Lacombe Experimental Farm, Alta. (Pharis et al. 1957) 23
18. Comparison of mineral soil exposed on and between logging roads and skidtrails in ESSF, ICH and IDF clearcuts in the Nelson Forest Region (Smith and Wass 1976) 25
19. Average percent cover of the three most prominent seeded grasses on lodgepole pine clearcuts near Kamloops, B.C., treated by windrowing and burning, broadcast burning, drag scarification and no site preparation (data from Hoyles 1977) 26
20. Effect of seeding forage plants on the establishment of lodgepole pine on burns in eastern Oregon (Pickford and Jackman 1944) 36
21. Trends in seeded species on burned ponderosa pine forestland in Oregon based on field inspections (Wilson 1949) 42
22. Average vegetative cover (%) between roads in clearcuts logged 3, 4 and 5 years prior to sampling in three biogeoclimatic zones in the Nelson Forest Region, B.C. (Smith and Wass 1976) 44
23. Native herbage yield after 3 growing seasons in relation to the extent of soil disturbance caused by logging in mixed coniferous forest of northeastern Oregon (Hedrick et al. 1968) 45
24. Average forage yields (1960–1961) from seeded and non-seeded forest range at Aspen Grove, British Columbia (Pringle and McLean 1962) 48
25. Estimated duration of grazing use on seeded clearcuts following logging in the Pacific Northwest 49
26. Improvement in livestock carrying capacity through clearcut logging and seeding of forest range in Oregon (Vavra 1983) 50
27. Forage consumed by cattle on bunchgrass, forest and clearcut summer range (July 31–September 12) in northeastern Oregon (Miller and Krueger 1976) 51
28. Average dry weight understory production for different canopy cover classes of lodgepole pine and Douglas-fir at Pass Lake, British Columbia (Dodd et al. 1972) 59

29. Dry weight biomass estimates of understory vegetation from different tree cover types in the IDF zone of southern British Columbia (Tisdale 1950) 59
30. Overstory basal area and understory production for 3 forest communities in the Black Hills of South Dakota (Kranz and Linder 1973) 59
31. Stocking rates and average daily gains for two clearcut and two forested ranges in the Pacific Northwest 68
32. Effect of stocking rate on cow and calf gains, per head and per hectare, on ponderosa pine range in Oregon (Skovlin et al. 1976) 68

FIGURES

1. Cattle distribution and biogeoclimatic zones of British Columbia 5
2. Percentage of total productive forest area for major species groups by Forest Region 10
3. Probabilities of occurrence in sample plots for eight plant groups on the Sleeping Child burn, Montana, 1962 to 1973 (Lyon 1976) 38
4. Live vegetation (native and seeded) and litter-density trends at two sites on a forest burn in the Black Hills, South Dakota. Each bar represents the yearly average of four plots (Orr 1970) 40
5. Dominant ground cover composition trends in terms of cover rank at two sites on a forest burn in the Black Hills, South Dakota. The three dominant species were ranked 3, 2, or 1 in descending order of abundance and proportion of ground cover to define general ground cover density and composition trends (Orr 1970) 43

1 INTRODUCTION

In recent years, increased demands have been made on the timber, range, wildlife and recreational resources of forests in western Canada and the United States (U.S.), leading to conflicts of interest between different user groups. Such confrontations have been particularly evident in the management of forests for both timber and range (Clark 1975; Kosco and Bartolome 1981). One major area of disagreement concerns the effect of grass and grazing on conifer regeneration in transitory range such as clearcuts and burns, as well as loss of forage production and summer grazing areas due to single-purpose logging and silvicultural practices.

A significant part of the problem stems from an incomplete understanding of forest ecology since effective multiple use planning depends on, amongst other things, the clear perception of cause and effect relationships between browsing and grazing animals and their environment (Riney 1966; Hall 1980). Incompatibility has also resulted from a lack of appreciation for differing objectives and the occasional failure to apply the principles of forestry "multiple use" and grazing "proper use" (Clark 1975). Predictions that grass-fed livestock on pasture and grazed forest range will contribute more to total beef production in the future due to increasing grain costs (Whelan 1974; Pimental et al. 1980) give impetus to the need for (1) a thorough comprehension of complex forage, timber, and cattle interactions to optimize multiple-resource yields, and (2) greater cooperation among resource planners, administrators and users.

Despite the awareness of problems perceived today regarding forestland grazing, differences of opinion have existed between forest and range managers for decades. In the early 1900's cattle were implicated as possible causative agents responsible for poor ponderosa pine reproduction in Arizona, New Mexico and central Idaho, but subsequent studies by Hill (1917) and Sparhawk (1918) showed that regulated grazing resulted in slight or negligible damage to pine seedlings.

Ingram (1928; 1931) investigated the use of native forage on Douglas-fir cut-over land in Washington and Oregon, and concluded that moderate grazing by sheep was not seriously inimical to forest regeneration and, indeed, was more than compensated for by the protection it afforded through reduced fire hazard. Reid (1947) wrote that although there was little specific information available concerning the effects of grazing on ponderosa pine in Washington and Oregon, it was doubtful that well managed grazing had any detrimental effect on tree reproduction. This view was shared by Morris (1947) who argued that there were little quantitative data to substantiate the contention that grazing had an undesirable effect on forest regeneration in Idaho and Montana, particularly if livestock were thought to induce damage by grazing or trampling seedlings.

In British Columbia (B.C.), much of the southern interior's open range was alienated by the turn of the century and the shortage of grasslands led to an increasing use and development of timber ranges for summer grazing (Tisdale et al. 1954; Select Standing Committee on Agriculture 1979). Early conflicts between foresters and graziers arose from the problem of forest ranges rendered inaccessible by fallen fire- or beetle-killed trees (Tisdale 1950; Hobbs 1954; McLean and Willis 1961). More recently, the seeding and grazing of reforested clearcuts has become a rather common practice, and has consequently brought forage and forest resource users into direct opposition (Clark and McLean 1974; Clark 1975; McLean and Clark 1980). The use of clearcut forest lands for range has not yet reached its full potential in this province, partly because of the unresolved controversy which remains between range and forest managers regarding the nature of tree, grass and grazing interactions on sites where both forest regeneration and forage production are concurrent management objectives.

The British Columbia Ministry of Forests has a mandate to intensify forest management, yet simultaneously encourage compatible recreational use and grazing for livestock (B.C. Min. For. 1980). Therefore, the question of possible incompatibility between forestry and ranching objectives is of considerable concern. Resolution of this issue ultimately depends on the acceptance of conclusive evidence derived from rigorous experimental studies (McLean 1979a).

The purpose of this review is to summarize the published literature on ecological aspects of tree/forage/livestock interactions on forest range in North America, and to identify research requirements applicable to British Columbia. Specific problem areas addressed in the study include:

(1) the establishment of seeded forages in logged environments (clearcuts, landings, skidtrails), with emphasis on species selection, seedbed preparation, environmental requirements for germination, and timing of seeding;
(2) competitive interactions between introduced grasses and trees, as well as between introduced grasses and native vegetation, on logged sites;
(3) impacts of grazing on seeded forages and coniferous tree seedlings;
(4) effects of silvicultural treatments on forage production in late successional forest stands.

The data base for this study was restricted primarily to published journal articles as well as government and university reports, research notes, manuals, texts, theses and dissertations. Some unpublished manuscripts were also used as references. External literature was reviewed to compensate for the paucity of relevant scientific information available within the province, and also to identify general principles from geographically widespread studies on forest grazing. Given the wide variation in dominant tree species, understory vegetation, climate, soils, and topography presented in the literature, the potential for extrapolating results from specific investigations to all biogeoclimatic zones in B.C. is discussed.

Primary sources of material outside of British Columbia included pertinent research from the shortleaf/loblolly and longleaf/slash pine communities of the southeastern United States (White 1973; Grelen 1978) and the ponderosa pine forests in the west (Reid 1965; Skovlin et al. 1976). Considerable experimental work was also examined from the mixed ponderosa pine/Douglas-fir/grand fir stands in central Oregon and southwestern Washington (Hedrick et al. 1968; Hall 1980; Krueger 1983). In the review, Pacific Northwest refers to British Columbia, Washington, Oregon, Idaho and western Montana unless otherwise specified.

2 CHARACTERISTICS OF FOREST RANGE ECOSYSTEMS IN BRITISH COLUMBIA

The term "rangelands" comprises that part of the land resource in native or improved state that has and retains the capability to afford a variety of products, values, uses or services including forage and water for wildlife and livestock. The remaining rangelands of British Columbia are mainly not susceptible to intensive cultivation because of various physical, environmental, economic, social or resource factors. The limiting factors may involve topography, slope, aspect, altitude, exposure, surface configuration or impediment, soil, precipitation, drainage, climate, plant cover or presence of resource uses or values other than forage.

TABLE 1. Range types on Crown land available for grazing in British Columbia ('000 ha) (B.C. Min. For. 1980)

RANGE TYPES	REGION[1]						
	NEL	KAM	CAR	PR GEO	PR RUP	VAN	TOTAL
Underdeveloped native range				576			576
Community Pasture				11			11
Reserve				148			148
Pasture development potential				35		35	70
Open Range	22	430	228		11		691
Open Forest	350	820	169		43		1382
Meadows		20	278		11		309
Forest	462	2500	2158		155		5275
Alpine	6						6
Total	**840**	**3770**	**2833**	**770**	**220**	**35**	**8468**

[1] Forest Regions: NEL = Nelson; KAM = Kamloops; CAR = Cariboo; PR GEO = Prince George; PR RUP = Prince Rupert; VAN = Vancouver.

NOTE: Prince George Region is the total of the Peace River and Prince George sub-regions.

Rangelands in British Columbia encompass a diversity of ecosystems, including alpine, grassland, meadow and forest plant communities (Table 1). The largest range type, in terms of areal extent, is forest range. Approximately 90% or 9 million ha of Crown range in British Columbia is under forest cover with scattered meadow openings (B.C. Min. For. 1980). These forested rangelands occur within numerous biogeoclimatic zones throughout the province, including the Sub-Boreal Spruce (SBS), Spruce/Willow/Birch (SWB), and Boreal White and Black Spruce (BWBS) zones in the north and the Interior Douglas-fir (IDF), Engelmann Spruce/ Subalpine Fir (ESSF), Ponderosa Pine/Bunchgrass (PPBG), Montane Spruce (MS), and Interior Cedar/ Hemlock (ICH) zones in the south (Table 2). The IDF, SBS and BWBS zones cover much of the land area grazed by livestock in the province (Figure 1), but published statistics indicating stock density by biogeoclimatic zone are not available.

Most forest grazing has historically taken place in the Douglas-fir forest type of the southern interior (Kamloops and Cariboo Forest Regions), as defined broadly by Tisdale (1950). Successive fires have resulted in the occupation of much of this forest type by a fire subclimax of lodgepole pine, with only limited areas remaining in Douglas-fir (Tisdale et al. 1954; Tisdale and McLean 1957). Although the Kamloops and Cariboo Forest Regions still continue to be primary grazing districts, range use has dramatically increased over the last decade in forested areas of the Prince George and Prince Rupert Forest Regions in north-central British Columbia (Table 3).

Forest range is defined by the Society for Range Management as wooded or forested vegetation suited for grazing livestock (Hall 1978). Timber management is often a major factor in the multiple use of forest range and silvicultural methods will largely determine the advantages or disadvantages for livestock, game, watershed and recreation values as well as the amount, kind and quality of timber products (Hall 1966; 1977).

Forest range may be divided into two basic categories depending on the absence or presence of an overstory:

(1) herb and shrub dominated forest range in early successional forest ecosystems; and
(2) tree dominated forest range in late successional and climax forest ecosystems.

Early successional forest ecosystems are represented by the plant communities which develop immediately after a disturbance such as timber harvesting or wildfire (Section 3). These communities are largely composed of residual or immigrant herbs and shrubs which gradually reoccupy the site and initially comprise most of the

TABLE 2. Biogeoclimatic zones and their utilization for domestic grazing in each of the Ministry of Forests' administrative regions (Wikeem 1983)

	FOREST REGION					
BIOGEOCLIMATIC ZONE	NEL	KAM	CAR	PR GEO	PR RUP	VAN
Alpine Tundra (AT)		X	X			X
Boreal White/Black Spruce (BWBS)				X		
Coastal Cedars/Pine/Hemlock (CCPH)						
Coastal Douglas-Fir (CDF)						
Coastal Western Hemlock (CWH)						
Englemann Spruce/Subalpine Fir (ESSF)	X	X	X			
Interior Cedar Hemlock (ICH)	X	X	X			
Interior Douglas-Fir (IDF)	X	X	X			
Mountain Hemlock (MH)						
Montane Spruce (MS)	X	X	X			
Ponderosa Pine/Bunchgrass (PPBG)	X	X	X			
Sub-boreal Spruce (SBS)			X	X	X	
Spruce/Willow/Birch (SWB)				X		

TABLE 3. Distribution of AUMs allocated on Crown range for all livestock (cattle, horses, sheep) by Forest Region 1969–1980

	Forest Region						
YEAR	Nelson	Kamloops	Cariboo	Prince George	Prince Rupert	Vancouver	Annual Total
1969	110,340	681,580		50,565			842,485
1970	97,890	674,667		49,285			821,842
1971	98,513	672,285		58,266			829,064
1972	91,473	322,493	330,983	41,998			786,947
1973	82,627	321,989	332,450	45,675			782,741
1974	81,706	320,110	349,013	57,793		616	809,238
1975	79,603	316,306	327,215	61,870	1,828	584	787,406
1976	77,681	315,953	332,466	86,551	1,584	401	614,636
1977	71,374	316,814	324,862	112,732	1,997	394	828,173
1978	74,021	313,062	351,672	130,482	2,044	327	871,608
1979	73,750	307,053	386,234	124,672	15,718	683	908,110
1980	74,971	321,302	367,408	140,538	26,415	608	931,242

Source: Ministry of Forests, Range Management Branch (Compiled June 1982).

primary production over the first few years (Section 3.2.3). Native species may sometimes be replaced or supplemented by the introduction of seeded domestic grasses and legumes for erosion control or forage (Sections 3.1.2 and 3.2.2).

Natural or artificial tree regeneration contributes little to community biomass during this period (Section 3.1.1). The juvenile conifer seedlings are vulnerable to competitive stress imposed by herbaceous and brush species (Section 3.2.1), as well as to trampling and browsing damage from livestock and wildlife (Section 3.3.2). These early successional communities are typically highly productive in terms of forage yields and grazing capacity (Section 3.3.1).

Late successional and climax forest ecosystems are characterized by varying degrees of overstory development and vertical stratification of the plant community (Section 4). Successional forests provide long-

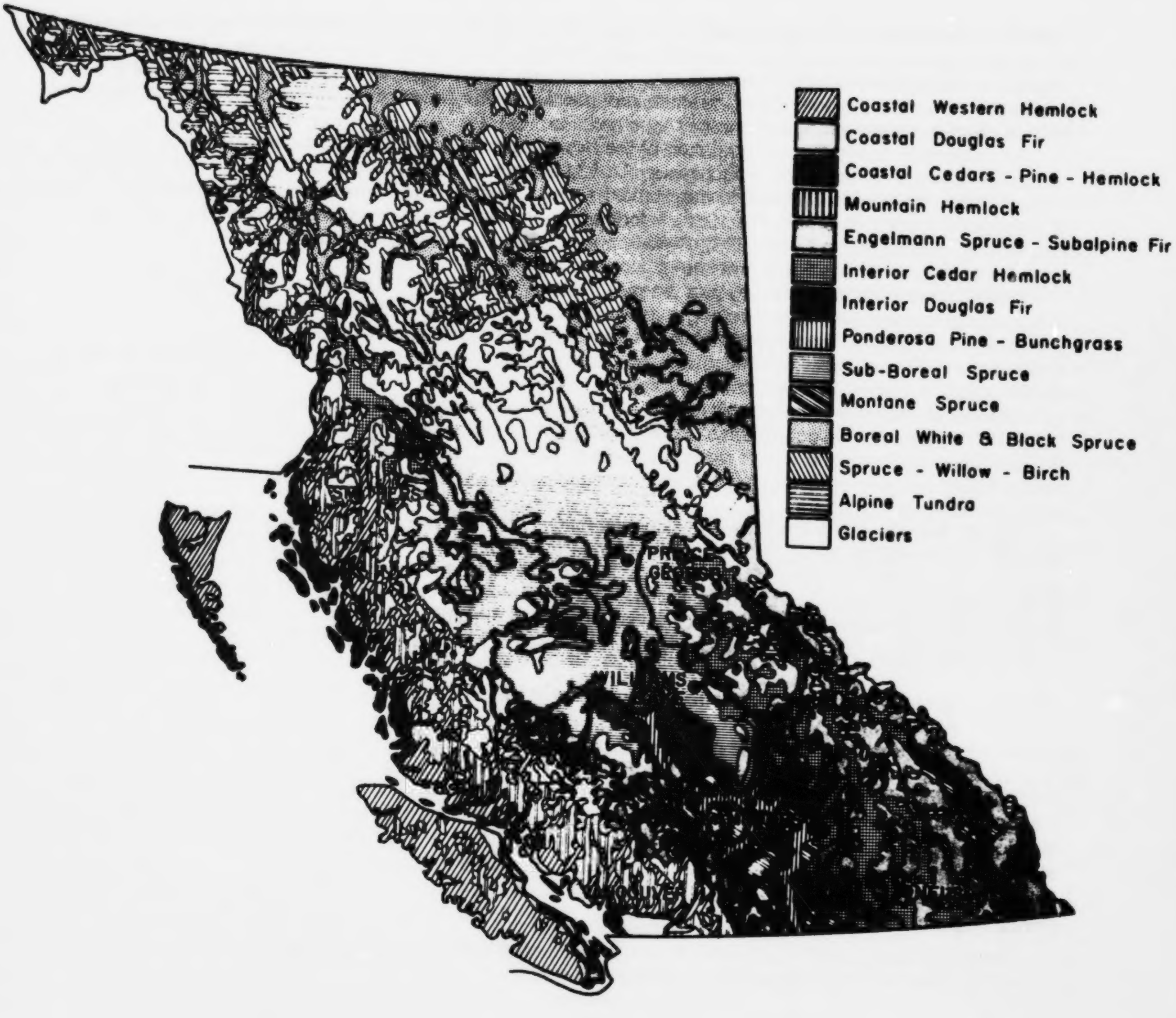
Coastal Western Hemlock
Coastal Douglas Fir
Coastal Cedars - Pine - Hemlock
Mountain Hemlock
Engelmann Spruce - Subalpine Fir
Interior Cedar Hemlock
Interior Douglas Fir
Ponderosa Pine - Bunchgrass
Sub-Boreal Spruce
Montane Spruce
Boreal White & Black Spruce
Spruce - Willow - Birch
Alpine Tundra
Glaciers

FIGURE 1. Cattle distribution and biogeoclimatic zones of British Columbia.

term grazing, but carrying capacity progressively decreases as forage production declines with a change in tree species composition from seral, low crown-cover lodgepole pine to a climax of densely-stocked, high crown-cover Douglas-fir, spruce or true firs (Hall 1977). Climax forests, often ponderosa pine, which are permanently suited for livestock grazing are usually found on sites with inherently low timber production. Such areas are often park-like and have sometimes been referred to as "open" forest (Select Standing Committee on Agriculture 1979; B.C. Min. For. 1980). Forage production is generally lower in tree-dominated plant communities than on early successional forest range (Section 4.2.1), and is influenced by silvicultural activities such as thinning or burning (Section 4.1). Similarly, livestock utilization of the forage resource in late successional and climax forest ecosystems is related to degree of canopy cover and silvicultural practices (Section 4.2).

The boundary drawn between early and late successional forest ecosystems is equivocal. A possible, but arbitrary, disjunction is the point at which the tree canopy drastically affects herbage production. Decreased forage yields have been observed quite soon after initiation of canopy development. For example, Krueger

(1981) reported that most forage reduction in Douglas-fir/ponderosa pine forests in eastern Oregon had occurred by the time the overstory reached 20 to 30% cover. However, the length of time and degree of cover required to cause substantial losses in forage productivity varies with the species, density and growth rate of the tree population, as well as the potential of the site to produce timber. Furthermore, conceptual and practical problems exist in quantitatively defining the phrase "substantial losses".

An intuitive or qualitative interpretation of the two categories is perhaps more useful for purposes of this review. On a temporal scale, early successional forest range may be considered to be the period of maximum herbage productivity immediately following timber harvest, during which time trees are in the regeneration phase of stand development (B.C. Min. For. 1980). In lodgepole pine stands, this period may be approximately 10 years (Basile and Jensen 1971; Lyon 1976). Synonymous terms used in the literature for this range type include temporary, transient, transitional and interim summer range.

Trees in the immature and mature stages of stand development (B.C. Min. For. 1980) indicate later successional forest ecosystems. Grazing units within these areas, as well as within suitable climax forest stands, are consonant with the formal definitions of forest range and grazable woodland given by Hall (1978) and Kothmann (1974), respectively. These ranges usually provide longer-term grazing than early successional communities, but at much lower stocking rates.

The predominant emphasis in this review is on tree/forage/livestock interactions in early successional forest range or "harvested forest ecosystems". Further geographic expansion of the grazing land base in most parts of B.C. depends on increased use of clearcuts (Select Standing Committee on Agriculture 1979; B.C. Min. For. 1980). Therefore, a knowledge of ecological interrelationships in these environments is of paramount importance to resource managers.

For 30 years or more, landings and skidtrails on Crown forest range near Kamloops have been manually seeded to domestic grasses by grazing permittees to encourage better livestock distribution and increase utilization of native vegetation (Stewart 1980). However, widespread aerial seeding of clearcuts to enhance forage yields has been undertaken by the B.C. Forest Service only within the last two decades (Clark and McLean 1974). Although not all clearcuts are suitable for domestic forage production, the figures presented in Table 4 suggest that this practice has not yet achieved its full potential in this province.

TABLE 4. Hectares of clearcut and seeded forestland in British Columbia, 1982, by Forest Region (B.C. Min. For. 1982)

Forest Region	Clearcut (ha)	Seeded (ha)	%
Cariboo	16,014	224	1.4
Kamloops	14,041	8,436	60.1
Nelson	8,826	1,300	14.7
Prince George	47,954	3,661	7.6
Prince Rupert	17,635	65	0.4
Total	**104,470**	**13,686**	**13.1**

3 TREE/FORAGE/LIVESTOCK INTERACTIONS IN HARVESTED FOREST ECOSYSTEMS

Forest and range resource managers involved in multiple use of Crown forestland are primarily concerned with three types of biological interaction in post-harvest plant communities:

(1) competition between regenerating tree seedlings and adjacent vegetation such as domestic grasses and/or native herbs and shrubs;
(2) competition between domestic forages and native vegetation;
(3) utilization of domestic and native forages, as well as trampling and browsing of tree regeneration, by livestock and wildlife.

Following timber harvest, tree establishment is initiated either naturally from local seed sources or artificially through direct seeding or planting. Native vegetation recolonizes the site through natural seeding or vegetative reproduction of residual plants, as well as through dispersed seed from invading species. Domestic forages are broadcast-seeded manually, mechanically or aerially.

Successful germination and establishment of trees and seeded forages depends largely on physical factors such as degree of site disturbance, nutrient and moisture availability, temperature, and amount and timing of precipitation. Once established, continued development of juvenile plants is related to their ability to withstand (1) biological competition from other members of the post-harvest plant community, (2) impacts associated with grazing, browsing and trampling by domestic and native herbivores, and (3) climatic stresses.

3.1 Establishment of Post-Harvest Forest Communities

Timber harvest exercises profound effects on forest physiognomy and ecology. Depending on the silvicultural system used and the species cut or replaced in mixed stands, the succeeding plant community will be substantially altered from its previous structure and composition (Spurr and Barnes 1973).

This is especially true of forest regenerating on logged sites which have been seeded to domestic forages for grazing purposes. In such multiple-use cases, the resource manager seeks to integrate the establishment and growth of both products. This requires a knowledge of the specific germination and juvenile growth requirements of the trees, grasses and legumes desired as codominants in the post-harvest plant community.

3.1.1 Trees

Natural tree reproduction depends on a number of factors, including seed source, production and dispersal, seedbed quality and environmental constraints (Noble and Ronco 1978). Artificial restocking is influenced by, among other things, the selection of species to seed or plant and the degree or method of site preparation prior to the regeneration phase. These two conditions can be manipulated by resource managers to encourage the compatible establishment of trees and domestic herbs on harvested sites.

3.1.1.1 Selection of Species

Guidelines for selecting suitable conifers to restock a logged area are based on the silvics of the species in relation to the environmental factors prevailing on the site. Pojar et al. (1982) considered the important factors in species selection to be "(1) ecological moisture and nutrient regimes, (2) humus form, (3) soil family particle size, (4) soil drainage, (5) effective rooting depth and (6) competing vegetation."

Frequently, choice of species depends on the former occupants of the site and advance or natural reproduction of these species is relied upon for reforestation. The assumption is that the natural distribution of a tree species reflects adaptation to a particular habitat within its range, as distinguished by specific ecological characteristics, and hence is the logical replacement after logging in that habitat. However, this is not necessarily true and, given the techniques for artificial regeneration and genetic improvement available to the silviculturist, species composition of the previous stand may be subordinate to economic or other considerations in reaching a final decision. In the following sections, commercially valuable tree species in British Columbia which are expected to interact with forage and cattle on forest range are identified and their silvics and regeneration requirements briefly described.

3.1.1.1.1 Distribution of Commercial Species

Most of the 28 commercial tree species in British Columbia (Appendix 8.1) can be categorized within species groups having similar ecological characteristics and taxonomic affinities. The nine major species groups recognized by B.C. Min. For. (1980) are balsam, cedar, fir, hemlock, larch, lodgepole pine, pine, spruce and deciduous (Table 5). The balsam species group contains the "true firs", while the fir group is represented solely by Douglas-fir.

TABLE 5. Tree species groups recognized by the British Columbia Ministry of Forests (B.C. Min. For. 1980; Mitchell & Green 1981)

Species Group	Species	Symbol
Balsam	Amabilis fir	Ba
	Grand fir	Bg
	Subalpine fir	Bl
Cedar	Western red cedar	Cw
Deciduous	Alder	D
	Aspen (trembling)	At
	Birch	E
	Maple	M
	Poplar (cottonwood)	Ac
Fir	Douglas-fir	Fd
Hemlock	Mountain hemlock	Hm
	Western hemlock	Hw
Larch	Alpine larch	La
	Tamarack	Lt
	Western larch	Lw
Lodgepole pine	Lodgepole pine	Pl
Pine	Jack pine	Pj
	Limber pine	Pf
	Western white pine	Pw
	Whitebark pine	Pa
	Yellow or ponderosa pine	Py
Spruce	Black spruce	Sb
	Engelmann spruce	Se
	Sitka spruce	Ss
	White spruce	Sw

NOTE: Scientific names of tree species in Appendix 8.1.

Statistics for the 1980 timber harvest (Table 6) indicate the importance of spruce and lodgepole pine to the British Columbia forest industry on a provincial scale. These two species groups are followed by balsam, Douglas-fir, hemlock and cedar, in that order.

The approximate geographical distribution of commercially valuable tree species or genera within British Columbia is illustrated schematically in Figure 2. The figure summarizes the percentages of total productive forest area covered by the major species groups on a regional basis.

Lodgepole pine is present throughout most of the province. It has a broad Cordilleran distribution, occurring in the CWH, CDF, ICH, SBS, BWBS, ESSF, MS and, rarely, in the MH biogeoclimatic zones (Krajina 1969). Lodgepole pine is a seral species, primarily of fire origin, and is usually replaced by spruce, Douglas-fir, western larch and/or "true firs" as succession proceeds (Illingworth and Arlidge 1960; Ogilvie 1969; Daubenmire 1978). However, lodgepole pine may be the climax species in dry parts of the Chilcotin (R.M. Strang, pers. com.)[1].

Spruce comprises a significant portion of the productive forest cover in the Prince George, Peace River and Bulkley-Northwest regions. White spruce, having a North American boreal distribution, is the most prominent species of this genus in the northern areas and is found in the BWBS, SBS, SWB, IDF and ICH zones (Krajina 1969; Ogilvie 1969). Engelmann spruce, a Cordilleran floristic element, is largely restricted to subalpine elevations in the south (Daubenmire 1978). It normally occurs in the ESSF, MS and IDF zones, and infrequently in the ICH (Krajina 1969). Extensive hybridization between these two species has taken place in central British Columbia (Garman 1957; Daubenmire 1978).

---

[1] Executive Director, B.C. Forest Research Council.

TABLE 6. Timber harvest ('000 cubic metres) and percentage of total productive forest area (in parentheses) by species group and Forest Region in interior British Columbia, 1980 (B.C. Min. For. 1980; 1981)

Forest Region	Biogeoclimatic Zones	Balsam	Cedar	Douglas Fir	Hemlock	Lodgepole Pine	Spruce
Nelson	ESSF, ICH, IDF, MS, PPBG	564	863	709	772	1,792	1,262
		(12)	(2)	(16)	(4)	(35)	(16)
Kamloops	AT, ESSF, ICH, IDF, MS, PPBG	934	516	1,640	389	2,505	2,267
		(9)	(3)	(27)	(3)	(35)	(16)
Cariboo	AT, ESSF, ICH, IDF, MS, PPBG, SBS	259	185	1,485	35	3,388	1,561
		(3)	(1)	(17)	(–)	(65)	(11)
Prince George	BWBS, SBS, SWB	1,365	78	273	28	4,347	7,833
		(9)	(–)	(–)	(–)	(32)	(37)
Prince Rupert	ESSF, SBS, SWB	1,185	328	–	1,500	2,275	1,831
		(18)	(11)	(–)	(23)	(27)	(17)
Total		**4,307**	**1,970**	**4,107**	**2,724**	**14,307**	**14,754**

The balsam group is represented mainly by subalpine fir in the interior of British Columbia. This species has a Cordilleran distribution and is present in the ESSF, MS, SBS, BWBS and ICH zones (Krajina 1969). It also occurs occasionally in the MH. Subalpine fir is often associated with white or Engelmann spruce as a climax co-dominant, although spruce is usually predominant in mature stands (Ogilvie 1969; Daubenmire 1978).

Douglas-fir exists as two distinct populations in B.C.: coastal and interior. Both varieties are Cordilleran elements, with the coastal population occurring in the CDF and CWH zones, and the interior population in the IDF, PPBG, ICH, MS, SBS and sometimes in the ESSF (Krajina 1969). Interior Douglas-fir is mainly found in the southern Forest Regions.

Hemlock and cedar are Pacific floristic elements (Krajina 1969). Western hemlock is common at lower elevations in the CWH, CDF and ICH zones, and is sometimes present in the MH, IDF and ESSF (Krajina 1969; Daubenmire 1978). Mountain hemlock is a subalpine species in the MH, CWH and ESSF zones. Western red cedar is found in the CWH, CDF, ICH and IDF, as well as at lower elevations in the ESSF and MH (Krajina 1969). Both cedar and hemlock are of considerably more importance on the coast than in the interior of British Columbia.

Elevation and aspect significantly affect the distribution of these conifers. McLean and Holland (1958) noted a transition from Douglas-fir and white spruce to western red cedar and western hemlock at about 945 m, and from cedar/hemlock to Engelmann spruce and subalpine fir above 1100 m in the upper Columbia Valley. Similarly, McLean (1970) identified a vertical gradient in the Similkameen Valley, with ponderosa pine below 900 m, Douglas-fir and lodgepole pine from 900–1200 m, and subalpine fir, Engelmann spruce and mountain hemlock above 1200 m.

3.1.1.1.2 Regeneration and Silvics

Clearcut logging is the predominant silvicultural system practised in all Forest Regions of interior British Columbia (B.C. Min. For. 1980). The establishment of essentially even-aged forest stands after clearcutting occurs either naturally from local seed sources or artificially by direct seeding and planting. Regeneration in naturally seeded stands is determined by the species and biology of residual or peripheral trees on the harvested site, but where artificial reproduction is contemplated the species chosen must (1) be adapted to the local environment and (2) show promise of the best net returns (Smith 1962).

Other silvicultural systems are sometimes prescribed to achieve specific management objectives. For example, selection cutting is common in the PPBG zone in Kamloops to remove over-aged, deformed and suppressed trees, thereby allowing release and recruitment in the gaps created, and maintaining productive, uneven-aged stands. This system is also prescribed for dry IDF subzones in the Kamloops, Cariboo and Nelson Forest Regions to avoid site damage, regeneration problems and adverse harvesting impacts on associated forest values (M.B. Clark, pers. com.)[2].

---

[2] Research Forester, Kamloops Forest Region, B.C.M.O.F.

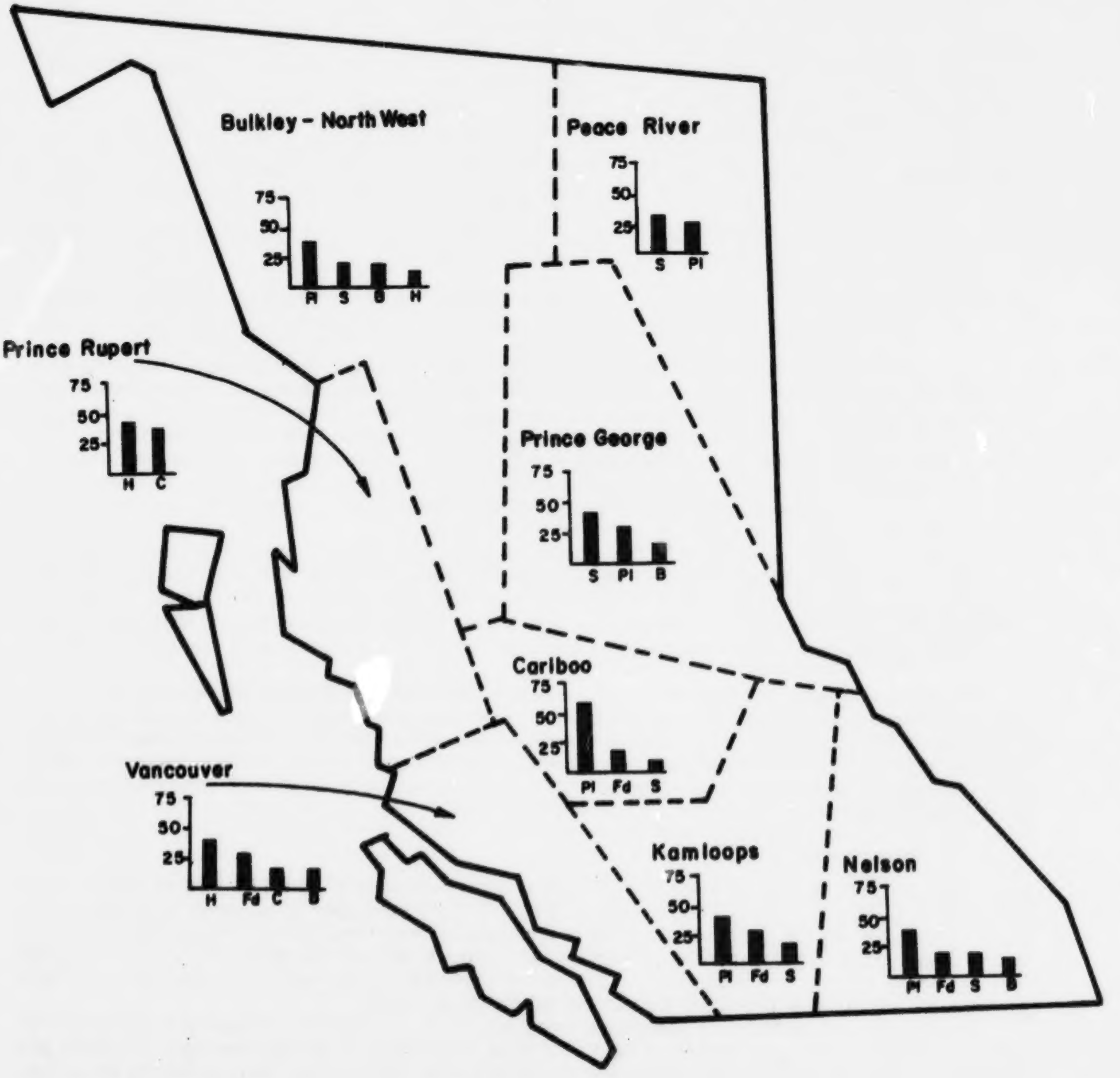
Bulkley - North West
75
50
25
Pl
S
B
H
Peace River
75
50
25
S
Pl
Prince Rupert
75
50
25
H
C
Prince George
75
50
25
S
Pl
B
Cariboo
75
50
25
Pl
Fd
S
Vancouver
75
50
25
H
Fd
C
B
Kamloops
75
50
25
Pl
Fd
S
Nelson
75
50
25
Pl
Fd
S
B

FIGURE 2. Percentage of total productive forest area for major species groups by Forest Region.

Tree species often naturally or artificially replaced on forest range in British Columbia are shown in Table 7. The most common species include lodgepole pine, Douglas-fir, Engelmann spruce and subalpine fir. Western larch is of significance in the Nelson and Kamloops Forest Regions (PPBGc, MSa, MSb, ICHc) as an alternative to Fd, Pl or Py, while mountain hemlock may be substituted for Se or Bl in the ESSFb and western hemlock for Fd, Pl or Se in the ICHa (Utzig et al. 1983). Western red cedar is naturally restocked in the ICH and wetter parts of the IDF zone (Silvicultural Guidelines, Kamloops Forest Region, Unpublished.). Ponderosa pine is regenerated primarily in the PPBG as well as in the drier portions of the IDF.

TABLE 7. Tree species occurrence by biogeoclimatic zone on forest range in British Columbia (Mitchell & Green 1981; Pojar et al. 1982; Utzig et al. 1983)

Biogeoclimatic Zone	Tree Species[1]									
	Bl	Cw	Fd	Hm	Hw	Lo	Pl	Py	Se	Sxw
ESSF	X			X			X		X	
ICH	X	X	X		X	X	X		X	
IDF		X	X				X	X		X
MS	X		X			X	X		X	
PPBG	X			X		X				
SBS	X			X						

[1] Symbols defined in Table 5; Sxw = White/Engelmann spruce hybrid.

Silvicultural practices vary from region to region, and from one biogeoclimatic zone to another. However, some generalizations are possible. Lodgepole pine is usually regenerated naturally in all Forest Regions, although planting occurs to different degrees in Kamloops and Nelson. Engelmann and white spruce are generally planted; however, it has been reported that about half of the spruce reproduction in Kamloops is through natural means (B.C. Min. For. 1980). Douglas-fir is planted in the Nelson, Cariboo and Kamloops Forest Regions but natural regeneration of this species is also significant, especially in the Cariboo. Subalpine fir has been experimentally planted in the Kamloops wet-belt, though spruce is usually prescribed. Natural hemlock regeneration is common in Prince Rupert on cedar/hemlock sites and, while hemlock is generally considered to be a weedy species in the Cariboo, natural cedar regeneration is acceptable on wet sites in this region where planting spruce would be unsuccessful.

On a provincial scale, the tree species which will most likely be involved in interactions with cattle and domestic forages include lodgepole pine, Douglas-fir, Engelmann and white spruce, and subalpine fir. The silvics of these species are summarized in Table 8. Of particular significance is the importance of mineral soil to successful germination of these conifers (Eis 1965; Dobbs 1972; Noble and Ronco 1977). As discussed later (Section 3.1.2.2.1), exposed mineral soil is also believed to be necessary for satisfactory establishment of forage grasses and legumes. Thus, appropriate seedbed preparation may encourage compatible production of trees and domestic forages on harvested sites.

3.1.1.2 Site Preparation

Prior to natural or artificial regeneration of desirable tree species some form of site preparation is usually necessary to:

(1) provide a suitable medium for seedling establishment,
(2) remove physical obstacles to planting,
(3) retard competing vegetation,
(4) reduce slash hazard,
(5) alleviate soil compaction and improve drainage, and/or
(6) control disease.

The layer of unincorporated organic matter which remains after logging does not make a good seedbed for most small seeded species, especially if exposed to desiccation and heating by the sun or if too thick for roots to reach mineral soil quickly (Smith 1962). Bare soil is usually much more favourable. Scarification and prescribed burning are two general methods for eliminating or reducing the dead organic matter on the forest floor and exposing mineral soil.

TABLE 8. Abbreviated silvics of common commercial tree species on forest range in British Columbia

	Species				
Factor:	Pl	Se	Sw	F	Bl
Germination:	mineral soil	mineral soil	mineral soil	shallow litter/ mineral soil	mineral soil
Moisture Requirements:	mod.	mod.	mod.	low to mod.	mod.
Nutrient Requirements:	low to mod.	mod. to high	mod.	mod. to high	high
Elevational Range (m):	500–2000	>1000	<1000	400–1500	>1000
pH Range:	5–6.5	4–5	4–5	5–7	5.5–6.5
Shade Tolerance:	low	mod.	mod.	mod.	high
Frost Tolerance:	mod.	mod.	mod.	low	high

Primary Sources:
Fowells (1965); Silvicultural Guidelines, Kamloops Forest Region (Unpublished).

Secondary Sources:
Lodgepole pine (Pl): Baker (1949); For. Res. Council B.C. (1983); Tackle (1959); Armit (1966).
Engelmann (Se) and *white spruce* (Sw): Baker (1949); Smith (1955); Sutton (1969); Dobbs (1972); Noble and Ronco (1978); Eis (1965); Noble and Alexander (1977).
Douglas-fir (F): Baker (1949); Strothman (1972).
Subalpine fir (Bl): Baker (1949); Eis (1965); Ogilvie (1969).

3.1.1.2.1 Scarification

In the interior of British Columbia scarification generally refers to seedbed preparation, while treatment of a site for planting is called mechanical site preparation (Dobbs 1972). Scarification consists of removing the humus and litter layers or mixing them with the mineral soil by mechanical action. Several different methods of scarification or mechanical site preparation are applied in British Columbia including blade, drag, and spot and row scarification (Glen 1979; Forest Research Council of B.C. 1983.)

Blade scarification involves the use of a brush or V-blade attached to a crawler tractor to break up logging slash and expose mineral soil. The method is used almost exclusively on spruce sites (Dobbs 1972). Arlidge (1967) pointed out that for best results spruce should be seeded naturally or artificially on scarified areas not later than one growing season after scarification. Because little surface organic matter is left in place following this procedure, however, there is some question as to the effect of blade scarification on soil fertility (Herring and McMinn 1980).

Drag scarification is the use of anchor chains or "sharkfin" drums to fragment slash and to loosen or mix the duff and topsoil. Anchor chains are used primarily to prepare the site for natural lodgepole pine regeneration, while sharkfin drums serve both this purpose and to make trails in areas designated for planting. Drag scarification promotes cone opening and seed release by depressing the cone-bearing slash close to the ground where radiant heat from the earth can break the resin bond sealing the serotinous lodgepole pine cones. Drag scarification, like wildfire, simultaneously disturbs the organic forest floor and leaves a receptive seedbed but, unlike a wildfire, does not destroy cones or seeds. This treatment is commonly used on lodgepole pine sites in the Prince George, Cariboo, and Kamloops Forest Regions, as well as the Bulkley-Northwest portion of the Prince Rupert Region (B.C. Min. For. 1980).

Spot and row scarification is limited in British Columbia and usually is applied in conjunction with planting. The method disturbs relatively small surface areas, exposing microsites of mineral soil or well-decomposed litter which favour the survival of young seedlings.

The areas treated in British Columbia in 1982 by drag and blade scarification are presented in Table 9. Drag scarification has clearly been the predominant method of preparing a site for natural regeneration, while blade scarification has most often been employed prior to planting.

The amount of mineral soil exposed by scarification may be confined to about only 30% of the total area because of slash, standing trees and accumulations of stripped topsoil and organic residue (Dobbs 1972). In addition, heavy scarification of the soil may lead to severe depletion of nutrients, excess stocking of pine seedlings or overwhelming growth of weeds. Scarification guidelines for integrated successful establishment of both trees and forage plants together on clearcut forest range are presently unavailable.

TABLE 9. Site preparation by scarification for natural regeneration and planting on Crown land, 1981–82, by Forest Region (B.C. Min. For. 1982)

Forest Region	Natural Regeneration		Planting	
	Drag (ha)	Blade (ha)	Drag (ha)	Blade (ha)
Cariboo	427	0	44	0
Kamloops	343	756	111	1,066
Nelson	552	1,269	157	426
Prince George	5,813	125	4	3,550
Prince Rupert	1,486	0	236	0
Total	**8,621**	**2,150**	**552**	**5,042**

3.1.1.2.2 Prescribed Burning

The use of regulated fires to minimize or eliminate the unincorporated organic matter of the forest floor or undesirable vegetation is called prescribed or controlled burning (Smith 1962). Slash burning involves much heavier concentrations of fuel than normally occur on the forest floor, but is often regarded as simply one type of prescribed burn. Site preparation through controlled fires in British Columbia usually takes the form of broadcast burning, bunching (piling) and burning, and spot burning (Forest Research Council of B.C. 1983).

In broadcast burning the slash on clearcuts is burned as it lies, within prepared fire lines. Much of the remaining vegetation, including undesirable plants, is destroyed. The extent to which mineral soil is exposed depends principally on the thickness of the humus layer and the moisture content of the forest floor at the time of burning. Usually an ample amount of mineral soil is exposed, and areas where fires burn with such intensity as to damage the physical properties of the soil are rarely large enough to be of much significance (Tarrant 1956). However, measurable differences in certain physical and chemical soil properties have been documented between burned and unburned sites. For example, Beaton (1959) found that soil porosity, infiltration rates, acidity, organic matter and total nitrogen were all reduced on burned timber range near Kamloops, B.C., while bulk density, temperature, total phosphorus and CO_2-soluble calcium increased. The loss of nitrogen to the atmosphere during burning may sometimes be compensated for by the activity of N-fixing organisms in the soil stimulated by the sudden release of calcium and other elements following the burn (Smith 1962).

Slash is sometimes windrowed along mechanically constructed lines or bunched into irregular piles prior to burning to clear the site for regeneration. The latter, referred to as "bunching and burning", is most commonly used where stumps, rocks or standing trees preclude the collection of logging debris into continuous rows.

In spot burning, a modification of broadcast burning, only patches with slash dense enough to burn without piling are ignited. It is restricted to situations where there is little danger of the fire spreading. The probability of successful spot burning on a planned basis for natural regeneration is extemely doubtful due to the difficulty in assessing the pattern and intensity of the fire after ignition (Forest Research Council of B.C. 1983).

Broadcast burning and windrowing and burning are commonly used for spruce site preparation in the Prince George and Prince Rupert (Bulkley-Northwest) Forest Regions. They are also practised to varying degrees in Kamloops and the Cariboo, but very little burning (especially broadcast) has been carried out in the Nelson Forest Region in recent years (B.C. Min. For. 1980). Dobbs (1972) pointed out that although prescribed burning has been successfully used for seedbed and site preparation in many parts of North America, results obtained on spruce sites in B.C. have been disappointing.

Burned seedbeds were generally inferior to mineral soil beds for white spruce, lodgepole pine and Douglas-fir (Dobbs 1972). Some burning occurs on lodgepole pine sites (Forest Research Council of B.C. 1983), particularly in areas with moderate to heavy slash or windfall (B.C. Min. For. 1980), but the majority of cones within the slash can be destroyed. The blackened surfaces remaining after broadcast burning, with their increased heat absorption properties, may increase surface temperatures to lethal levels for seeds, germinants or planted stock (Utzig et al. 1983). This consideration is of particular relevance to Douglas-fir seedling establishment (Fowells 1965).

Site preparation by prescribed burning on Crown land in British Columbia for 1982 is summarized in Table 10. Broadcast burning was used most often prior to planting, while bunching and burning was frequently employed on sites left to natural regeneration. In general, scarification was the most widely practised method of seedbed preparation for natural reproduction, and burning was the predominant form of site treatment for planting purposes (Tables 9 and 10, respectively).

TABLE 10. Site preparation by burning for natural regeneration and planting on Crown land, 1981-82, by Forest Region (B.C. Min. For. 1982)

Natural Regeneration

Forest Region	Broadcast Burned (ha)	Bunched, Burned (ha)	Windrowed, Burned (ha)	Spot Burned (ha)
Cariboo	0	1,266	0	0
Kamloops	31	446	198	37
Nelson	0	737	0	0
Prince George	58	88	249	60
Prince Rupert	0	0	0	947
Total	**89**	**2,537**	**447**	**1,044**

Planting

Forest Region	Broadcast Burned (ha)	Bunched, Burned (ha)	Windrowed, Burned (ha)	Spot Burned (ha)
Cariboo	1,528	2,304	55	0
Kamloops	1,806	574	237	294
Nelson	419	0	0	24
Prince George	8,741	896	2,984	0
Prince Rupert	2,596	259	3	0
Total	**15,090**	**4,033**	**3,279**	**318**

3.1.2 Forages

The seeding of domestic grasses and legumes on skidtrails, landings, logging roads and wildfire sites has been a common practice for several decades on forest range in the Pacific Northwest (Christ 1934; Pickford and Jackman 1944; Rummell and Holscher 1955; McClure 1958; Denham 1959; Eddleman and McLean 1969; Clark and McLean 1974). However, it is only recently that increased clearcut felling in the British Columbia interior, as well as elsewhere in the northwest, has led to opportunities for using these large cutover blocks for forage production.

The seeding of domestic species may provide a number of grazing benefits, including increased forage production, increased palatability and nutritive value of forage, improved distribution of livestock, extension of grazing area, and extension of grazing season (McLean and Bawtree 1971). Other objectives commonly stated for seeding disturbed forest range concern erosion control, increased soil fertility, prevention of weed invasion, reduced logging road maintenance costs, minimized fire hazard and improved aesthetics of the area.

The successsful establishment of grasses and legumes in the post-harvest plant community is contingent upon the appropriateness of the species selected for seeding, the nature and quality of the seedbed, the timing and rate of seeding, weather and predation. The species chosen must be adapted to the physical environment characterizing the site, primarily the climate, chemical status of the soils and soil moisture availability. Seedbed quality is determined largely by the degree and type of site preparation for tree regeneration. Site treatments will differ on heavily compacted skidtrails, landings and logging roads and the relatively uncompacted soils elsewhere on harvested sites. The timing and rate of seeding is mainly dependent upon the species composition of the mix and seeding objectives.

3.1.2.1 Selection of Species

The outcome of seeding operations depends to a considerable extent on the selection of species and varieties to be included in the sowing mix for a given site. Adaptation to the climate and soils of a particular biogeoclimatic subzone or ecosystem association is essential for juvenile survival and plant growth. Even within a small area, denuded ground presents a variety of microsites, from favourably moist soils to much drier exposed ridges, and no one species is capable of efficiently exploiting all potential habitats.

Rapidly-starting grasses are needed to stabilize the soil, while deep-rooted perennials are required to prevent erosion, provide long-term forage and retard the invasion of undesirable weedy species. Since portions of the disturbed ground may be heavily shaded, plants having some degree of shade tolerance should be in the mixture. Legumes are often recommended because it is generally believed they enrich the store of available soil nitrogen essential for normal and vigorous plant growth. Furthermore, phenological differences between grasses and legumes may extend the seasonal grazing period.

3.1.2.1.1 Grasses

Published experimental research investigating the germination and early survival of seeded grasses on logged or burned forestland in British Columbia is scarce. Only one published study was found dealing specifically with this province. Anderson and Elliott (1957), working in the Peace River region of northern British Columbia, provided data on the establishment of creeping red fescue, Kentucky bluegrass, smooth bromegrass, timothy and crested wheatgrass on burned coniferous/deciduous forest soils. Five years after seeding, visual observation revealed that the first three species were best adapted to the burned site, while timothy established satisfactorily only where moisture was abundant. Crested wheatgrass was found to be unsuitable.

On the other hand, several publications are available which give general guidelines for selecting grass species to seed on disturbed forestland in British Columbia (Pringle and McLean 1962; McLean and Bawtree 1971; Elliott and Baenziger 1977; Carr 1980; Mitchell and Green 1981; Utzig et al. 1983). These authors have recommended a number of species suited to a variety of habitat types and seeding objectives (Table 11; Scientific names in Appendix 8.2). However, data substantiating these recommendations were not found in the published literature.

All of the domestic grasses listed in Table 11 have been sown either experimentally or operationally for erosion control and forage production on forest range in Idaho, Oregon and Washington (Christ 1934; Hafenrichter et al. 1949; Wilson 1949; Dyrness 1967; Kidd and Haupt 1968; Anderson and Brooks 1975; Klock et al. 1975; Helvey and Fowler 1979). Species which have most frequently been reported in the literature include smooth bromegrass, orchardgrass, timothy and crested wheatgrass. These graminoids appear to be the most widespread and consistently successful of the numerous species seeded.

The American literature cited in Table 11 was classified in terms of approximate B.C. biogeoclimatic zone equivalents, based on the composition of dominant tree species. It was found that most of the information from outside the province was of direct relevance only to the PPBG and IDF zones. Very little pertinent data were available for the ESSF, MS, ICH, SBS and BWBS biogeoclimatic zones.

Although the objectives of erosion control and forage seedings are different, the seed mixes can sometimes be quite similar in composition. For example, the species recommended for stabilization of logged or burned forest in Oregon were identical to those recommended for interim forage on these sites (Berglund 1976). In wetter habitats these species included timothy, orchardgrass, Italian ryegrass and mountain bromergrass. Crested wheatgrass, big bluegrass, hard fescue and intermediate wheatgrass were suggested for drier environments.

Ministry of Forests staff in the Nelson Region of southeastern British Columbia were somewhat more discriminating in their recommendations, providing nine grass/legume seed mixes for use in logged/burned areas depending on objectives and ecosystem association (Utzig et al. 1983). However, two common forage grasses, timothy and crested wheatgrass, were included in their "Spruce/Fir" and "Dry Sod-forming" erosion control mixes, respectively.

Grasses which have been seeded for grazing purposes on forest range are summarized in Table 12. Most of these species have a "bunch" growth habit, which is usually considered more acceptable than the rhizomatous habit in situations where both tree regeneration and pasturage is wanted (Gjertson 1949). In general, sod-forming grasses are preferred for erosion control even though certain species, such as smooth brome, are valuable forage plants and often appear in forest range mixes for that purpose.

Timothy and orchardgrass have frequently produced excellent stands in seedings throughout the northwest. They are rapid-starting bunchgrasses adapted to broadcast seeding because their small seeds withstand little soil coverage (Gjertson 1949). They tolerate a wide spectrum of soil fertilities and textures, but generally prefer moist ground (McLean and Bawtree 1971). The two species are cold-resistant and orchardgrass is shade-tolerant. Although both timothy and orchardgrass are highly palatable, the latter tends to become coarse and harsh when underutilized.

Smooth bromegrass establishes successfully on well-prepared seedbeds, but in reseeding experiments the resultant stands have been poor (Christ 1934). The same difficulty was experienced in obtaining stands of crested wheatgrass. In both cases, it was believed that the large seeds did not become sufficiently covered with soil when broadcast seeded, and the young germinants were susceptible to drought and heat-induced mortality.

TABLE 11. Grass taxa seeded on burned/logged forest in the Pacific Northwest for erosion control and forage production

Species		Bibliographical Sources and Geographical Locations[1]																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Total
Bentgrass,	Colonial						X												X		2
	Highland															X					1
	Redtop				X	X			X										X		4
Bluegrass,	Big			X	X				X				X								4
	Bulbous																			X	1
	Canada				X	X							X								3
	Kentucky				X	X										X	X				4
Bromegrass,	Mountain			X												X			X	X	4
	Smooth		X	X	X	X			X	X		X	X	X	X	X	X	X	X	X	15
Canarygrass,	Reed				X	X															2
Fescue,	Chewing's						X			X						X			X		4
	Creeping red		X		X		X	X						X					X		6
	Hard			X	X						X							X			4
	Meadow				X	X															2
	Sheep				X	X			X	X											4
	Tall			X	X				X										X		4
Foxtail,	Meadow				X																1
Needlegrass,	Green								X				X								2
Oatgrass,	Tall				X	X			X	X								X		X	6
Orchardgrass				X	X	X			X	X	X		X	X	X	X	X	X	X	X	14
Ryegrass,	Annual			X	X	X	X														4
	Perennial			X	X	X	X						X							X	6
Timothy		X		X	X	X			X	X			X	X	X	X	X	X	X	X	14
Wheatgrass,	Beardless								X				X			X					3
	Crested	X		X	X	X			X	X		X		X	X	X	X		X	X	13
	Intermediate	X		X	X							X	X					X	X		7
	Pubescent				X				X				X					X			4
	Siberian				X								X								2
	Slender					X							X		X	X					4
	Streambank				X								X								2
	Tall			X	X								X								3
Wildrye,	Altai														X						1
	Blue				X								X					X			3
	Russian				X								X		X						3

[1] BIBLIOGRAPHICAL SOURCES AND GEOGRAPHICAL LOCATIONS

1. Anderson & Brooks (1975); Oregon; burned (PPBG, IDF)
2. Anderson & Elliott (1957); B.C.; burned; (BWBS)
3. Berglund (1976); Oregon; burned/logged (PPBG, IDF)
4. Carr (1980); B.C.; logging roads (PPBG, IDF, ESSF, SBS, ICH)
5. Christ (1934); Idaho; burned (PPBG, IDF, ICH)
6. Dyrness (1967); Oregon; logging roads
7. Elliott & Baenziger (1977); Alta., B.C.; burned (BWBS)
8. Evanko (1953b); Wash.; burned (IDF, ESSF)
9. Gjertson (1949); Oregon, Wash.; logging roads (PPBG)
10. Helvey & Fowler (1979); Oregon; burned (ESSF, MS)
11. Kidd & Haupt (1968); Idaho; logging roads (PPBG, IDF)
12. Klock et al. (1975); Wash.; burned (PPBG, IDF)
13. McLean & Bawtree (1971); B.C.; burned/logged (PPBG, IDF, ESSF)
14. Mitchell & Green (1981); B.C.; logged (PPBG, IDF, MS, ESSF)
15. Pickford & Jackman (1944); Oregon; burned (IDF)
16. Pringle & McLean (1962); B.C.; burned/logged (PPBG, IDF)
17. Rummell & Holscher (1955); Oregon, Wash.; burned/logged (PPBG)
18. Utzig et al. (1983); B.C.; logged (IDF, PPBG, ICH, MS, ESSF)
19. Wilson (1949); Oregon; burned (PPBG)

Smooth brome is very palatable to livestock, but orchardgrass and timothy are generally preferred to the wheatgrasses when present in mixed stands (Christ 1934).

Several other species show promise but have not been sufficiently tested. Among these are creeping red fescue, tall oatgrass, perennial ryegrass and intermediate wheatgrass. Rhizomatous creeping red fescue furnishes more ground cover than bunchgrasses, but is not as aggressive as smooth brome (Elliott and Baenziger 1977). It grows on a wide range of soil types and is practically unaffected by frost. The species has been successfully established on burns in the Peace River country of northern British Columbia and Alberta

TABLE 12. Agronomic characteristics of forage grasses commonly seeded on forest range in the Pacific Northwest

Species		Growth Habit	Longevity	Speed of Establishment	Palatability for Livestock	Adaptation to Climate and Environment
Bentgrass,	Redtop	sod	long	fast	poor	(15)[1] wet; drought, cold and acid tolerant
Bluegrass,	Big	bunch	long	slow	good	(2) dry-moist; cold and drought-tolerant
	Canada	sod	long	slow	poor	(16) moist-wet; cold and drought-tolerant
	Kentucky	sod	long	slow	poor	(17) wet; shade-tolerant
Bromegrass,	Smooth	sod	long	fast	good	(3) moist; cold-hardy
Canarygrass,	Reed	bunch	long	slow	fair-good	(18) wet; cold-hardy, not shade-tolerant
Fescue,	Hard	sod[2]	long	slow	fair	(7) dry-moist; very cold-hardy
	Meadow	bunch	medium	fast	good	(14) moist-wet; cold and shade-tolerant
	Sheep	bunch	long	slow	fair	(6) dry; drought-tolerant
	Tall	bunch	long	fast	fair	(11) wet; cold-hardy
Oatgrass,	Tall	bunch	medium	fast	good	(5) dry-moist; cold and shade-tolerant
Orchardgrass		bunch	long	fast	good	(12) moist-wet; cold-hardy, shade-tolerant, not drought-resistant
Ryegrass,	Italian	bunch	short	fast	good	(8) moist; not cold, heat or drought-resistant
	Perennial	bunch	short	fast	good	(9) moist; not cold-hardy
Timothy		bunch	long	fast	good	(13) wet; cold-hardy
Wheatgrass,	Crested	bunch	long	slow	fair	(1) dry; drought, cold and shade-tolerant
	Intermediate	sod	long	fast	fair	(10) dry-moist; frost-tolerant
	Slender	bunch	short	fast	fair	(4) dry; cold-hardy

Source: Berglund (1976); Carr (1980); Christ (1934); McLean and Bawtree (1971); Mitchell and Green (1981); Pringle and McLean (1962); Utzig et al. (1983).

(Anderson and Elliott 1957; Elliott and Baenziger 1977). Tall oatgrass is a rapid-growing, tall bunchgrass that is suitable as a "nurse crop" to (1) stabilize the soil against severe run-off and erosion, (2) provide shade on burned soils and reduce surface temperatures to levels that slower-developing seedlings of long-lived grasses can survive, (3) check the excessive establishment of tree seedlings and weedy species, and (4) provide forage for livestock during the period that the slower-growing, long-lived grasses are gaining a satisfactory foothold (Pickford and Jackman 1944; Wilson 1949).

Perennial rye is an easily-established, relatively short-lived, palatable caespitose species that can serve the same role as tall oatgrass (Christ 1934; Carr 1980). Christ (1934) reported that maintenance of perennial rye in seeded communities was poor and that the species was soon crowded out by more aggressive migratory plants. However, evidence and observations elsewhere indicate that perennial ryegrass can be strongly competitive and, if seeded too heavily in a mixture, may retard the establishment of other perennial grasses and legumes, particularly domestic species sown together with ryegrass (Stapledon and Davies 1928; Berglund 1976).

Intermediate wheatgrass is a rapid-developing, long-lived, rhizomatous perennial which has been successfully seeded on ponderosa pine forest range in central Colorado (Johnson and Hull 1949), central Idaho (Kidd and Haupt 1968) and northeastern Washington (Evanko 1953a). It is mildly sod-forming, does well in seed mixes, withstands moderate grazing and is more frost-tolerant than smooth brome (Berglund 1976; Carr 1980).

Bluegrass and bentgrass have been inconsistent in their performance. Big bluegrass and redtop were very productive on lodgepole pine burns in northeast Washington (Evanko 1953b) and big bluegrass has grown vigorously on ponderosa pine areas of Colorado (Johnson and Hull 1949). However, Gjertson (1949) reported that seedings of big bluegrass, Kentucky bluegrass, redtop and colonial bentgrass on forest range in Washington and Oregon have often failed.

---

[1] Integer in parentheses indicates approximate drought resistance of species in decreasing order from Crested wheatgrass (most drought resistant) to Reed canarygrass (least drought resistant); based on Pickford and Jackman (1944).

[2] Considered a sod-former by Carr (1980), but a bunchgrass with a dense, voluminous root system by Berglund (1976).

Although many of the species discussed above have been applied over a broad spectrum of geographic and physiographical settings, justification for their use has mainly been derived from experience and casual observation, rather than from controlled experimentation. Of the more than 20 papers reviewed on this subject, only 6 dealt specifically with species adaptation to site conditions, while 11 were handbooks recommending species which had been observed to produce satisfactory stands in past seedings. Experience is valuable in establishing initial guidelines but management prescriptions often demand more precise, consistent and scientifically-based information.

The few studies which have examined species adaptation to disturbed forest habitats vary considerably in quality. For example, Wilson (1949) investigated the germination and establishment of several grass species including crested wheatgrass, timothy, perennial ryegrass, orchardgrass and smooth brome on burned ponderosa pine forestland in Oregon. However, "success" was determined by ocular estimate and no quantitative comparative measurements of survival, cover, productivity, tiller number, vigour or plant height were presented.

The same problem of subjective measurement was also encountered in a study by Dyrness (1967), who tested a number of grass-legume mixtures for roadside soil stabilization in Oregon. Total vegetative cover was estimated visually, and species composition was simply noted as species present. Furthermore, because of competitive interactions among components of the mix, individual species adaptation could not be isolated in the data.

In a more recent study, Klock et al. (1975) experimentally seeded 28 grass species on a mixed conifer wildfire burn in northcentral Washington. Unfortunately, the results for single-species trials were confounded by the fact that all plots were fertilized and thus adaptation to the unmodified environment could not be determined. Further, in mixed-species sowings where the effects of fertilized/unfertilized treatments were separated, interspecific competition masked physical adaptation of individual species to the burned soil in unfertilized plots.

Evanko (1953b) used a more pragmatic approach. In his study, 14 forage grasses were individually broadcast-seeded in the ashes of a newly-burned lodgepole pine site in northeast Washington. The experimental area consisted of two blocks with opposite exposures. Plant vigour and stand density (number of plants per unit area) were recorded in early summer and fall of each year. Four years subsequent to seeding, only big bluegrass, sheep fescue, redtop and timothy were considered adequate in vigour and density on the dry, southwesterly exposed site. Soil and moisture conditions were more favourable on the northeast aspect and good to excellent stands of sheep fescue, tall oatgrass, redtop, pubescent wheatgrass, big bluegrass, smooth brome, orchardgrass, timothy and beardless bluebunch wheatgrass were produced.

Close inspection of Table 11 reveals that virtually all of the species listed have been sown, or are recommended for seeding, on both logged forestland and burns. One thus assumes that the species are equally well-adapted for germination, survival and growth on these two disparate environments. No conclusive evidence to support this assumption is given in the literature, however.

Similarly, several species are apparently adapted to a wide range of biogeoclimatic zones. For example, Carr (1980) recommended perennial ryegrass and creeping red fescue for erosion control seedings on permanently open logging roads in the ICH, ESSF, IDF, SBS and BWBS zones of British Columbia. In the Nelson Forest Region timothy and orchardgrass were recommended as forage species for all sites in the ICH, MS and ESSF zones as well as wetter areas in the IDF and PPBG (Utzig et al. 1983). However, quantitative data substantiating the success of these widely recommended species throughout the broad climatic and edaphic gradients encompassed by these biogeoclimatic zones is lacking in the published literature.

It may be argued that phenotypic and physiological plasticity of species exhibiting broad ecological tolerances permits establishment in divergent physical surroundings. However, the ultimate persistence of a species once established depends on its competitive proficiency in biological interactions with other members of the plant community, combined with its tolerance to grazing.

Certain species are uniquely adapted to specific ecological conditions. Crested wheatgrass, for example, is valuable for both forage and erosion purposes on very dry sites within the IDF and PPBG zones because of its great potential for resisting drought (Carr 1980; Smoliak et al. 1981a; Utzig et al. 1983). In the other extreme, reed canarygrass is useful in poorly-drained soils by virtue of its ability to tolerate flooding (Central Interior Forage Extension Committee 1981). Since this species is shade-intolerant and establishes slowly, however, Carr (1980) considered it to be more suited to pure stand sowing than mixed.

The production of timber as well as forage on logged forest range poses special problems. The grass species sown must be compatible with tree seedling requirements for establishment and growth. Competition for soil moisture can be quite severe on disturbed forest sites, so the seeding of rhizomatous, sodforming grasses with prolific, extensive root systems may be exceedingly detrimental to young trees with less root surface area available for moisture absorption (Gjertson 1949; Lane and McComb 1948; Sims and Mueller-Dombois 1968).

Clark and McLean (1979) investigated the effects of orchardgrass, smooth bromegrass, red fescue, hard fescue and crested wheatgrass on the establishment, survival and growth of lodgepole pine. All species, including pine, were sown in the same year. After four years no statistically significant differences were found between the grass species treatments and the unseeded control. It was concluded that the species tested had no apparent inimical effect on lodgepole pine seedlings (Clark and McLean 1979).

Interestingly, in an earlier study Clark and McLean (1975) noted that lodgepole pine seedlings were affected less when grown in competition with native rhizomatous pinegrass than with orchardgrass. They suggested that orchardgrass was quite competitive because of its ability to establish a good root system quickly. Berglund (1976) also cautioned that orchardgrass may be overly-competitive with tree seedlings.

Further discussion of grass/tree seedling interactions is reserved until Section 3.2.1. However, for present purposes, it should be noted that conclusive studies examining the effects of different forage grasses on conifer regeneration are rare, and a great deal of additional research into this subject is warranted if compatible, scientifically guided use of forests for timber and grazing is to be achieved.

3.1.2.1.2 Legumes

Leguminous species are often seeded on logged or burned forestland to increase the nitrogen content of the soil (McLean and Bawtree 1971; Carr 1980), although this has not been demonstrated experimentally in these environments. Legumes are superior to grasses in yield, protein, and minerals, but the danger of bloat to livestock from certain species usally results in reduced sowing rates for these plants in grass/legume forage mixtures (Christ 1934; Martin et al. 1976).

Less than a dozen legume species are seeded with any frequency in the Pacific Northwest (Table 13). As indicated in Table 13, however, most of the information pertaining to legumes has come from the PPBG and IDF zones, or their American equivalents. Little experimental data are available for biogeoclimatic zones in higher elevations or latitudes.

White clover, alsike clover, yellow and white sweetclovers, red clover and alfalfa have been cited most often in the literature, in that order. Biological and ecological characteristics of these and other legumes are summarized in Table 14, as well as approximate, relative ratings of their nitrogen-fixing ability and palatability. Under agronomic conditions, alfalfa and most clovers fix considerably more nitrogen than larger-seeded legumes (Martin et al. 1976), but this has not yet been demonstrated to be the case on disturbed forestland.

TABLE 13. Legume species seeded on burned/logged forest in the Pacific Northwest for erosion control, soil fertility and forage production

		Bibliographical Sources and Geographical Locations[1]															
Sources		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Alfalfa			X	X	X	X									X		5
Clover,	Alsike			X	X	X		X			X	X		X			7
	Red				X	X				X	X	X			X		6
	Subterranean			X	X												2
	White			X	X	X	X		X			X	X	X	X		9
Milkvetch,	Cicer				X					X							2
Sainfoin		X			X					X		X					4
Sweetclover	(Yellow and White)			X	X	X				X	X				X	X	7
Trefoil,	Big			X	X		X										3
	Birdsfoot			X	X		X			X							4

[1] BIBLIOGRAPHICAL SOURCES AND GEOGRAPHICAL LOCATIONS

1. Anderson & Brooks (1975); Oregon; burned (PPBG), IDF)
2. Anderson & Elliott (1957); B.C.; burned (BWBS)
3. Berglund (1976); Oregon; burned/logged (PPBG, IDF)
4. Carr (1980); B.C.; logging roads (PPBG, IDF, ESSF, SBS, ICH)
5. Christ (1934); Idaho; burned (PPBG, IDF, ICH)
6. Dyrness (1967); Oregon; logging roads
7. Evanko (1953b); Wash.; burned (IDF, ESSF)
8. Helvey & Fowler (1979); Oregon; burned (ESSF, MS)
9. Klock et al. (1975); Wash.; burned (PPBG, IDF)
10. McLean & Bawtree (1971); B.C.; burned/logged (PPBG, IDF, ESSF)
11. Mitchell & Green (1981); B.C.; logged (PPBG, IDF, MS, ESSF)
12. Pickford & Jackman (1944); Oregon; burned (IDF)
13. Pringle & McLean (1971); B.C.; burned/logged (PPBG, IDF)
14. Utzig et al. (1983); B.C.; burned/logged (IDF, PPBG, ICH, MS, ESSF)
15. Wilson (1949); Oregon; burned (PPBG)

TABLE 14. Characteristics of forage legumes commonly seeded on forest range in the Pacific Northwest

Species	Longevity	Speed of Establishment	N-Fixing Ability	Palatability for Livestock	Adaptation to Climate and Environment
Alfalfa	long-lived perennial	medium	good	good	moist habitats; drought-resistant; cold-hardy
Alsike clover	short-lived perennial	fast	good	fair	dry-wet; cold-hardy
Big trefoil	long-lived perennial	slow	fair	fair	wet habitats; mod. cold-hardy; acid-tolerant; drought-susceptible
Birdsfoot trefoil	long-lived perennial	slow	fair	fair	moist-wet; cold-tolerant; mod. acid-tolerant
Red clover	short to medium-lived perennial	fast	good	good	dry-moist; cold and shade tolerant; slightly acid-tolerant
Sainfoin	perennial	fast	poor	good	dry-moist; frost and drought-resistant
Subterranean clover	annual	slow	poor	fair	Moist habitats; not acid or cold-tolerant
White clover	long-lived perennial	fast	good	good	moist habitats; mod. cold-hardy
White sweetclover	biennial	fast	good	good	dry-wet; mod. drought and cold-resistant
Yellow sweetclover	biennial	fast	good	good	dry-wet; slightly less drought and cold-hardy

Sources: Carr (1980), Christ (1934), Hughes et al. (1951), McLean and Bawtree (1971), Martin et al. (1976), Pringle and McLean (1962).

White clover is a widely-adapted legume which has been recommended for sowing in the ESSF, ICH, IDF and MS biogeoclimatic zones in southern British Columbia (Mitchell and Green 1981; Utzig et al. 1983). It has also been recommended for erosion control mixes in the PPBG (Carr 1980). Experimental evidence substantiating these recommendations was not given.

According to Christ (1934), white clover usually establishes easily, produces an abundance of seed, withstands close grazing and does well on a wide range of soils in Idaho. It has also been sown and recommended as a forage legume in western, eastern and southeastern Oregon (Pickford and Jackman 1944; Berglund 1976; Helvey and Fowler 1979). Dyrness (1967) found that although germination and early establishment of white Dutch clover and New Zealand white clover was excellent in seeding trials on logging roadsides in western Oregon, vigour was generally low and plant density had decreased steadily by the end of the first growing season.

Anderson and Elliott (1957) observed that alsike clover quickly established on burns in the BWBS biogeoclimatic zone in northern British Columbia and spread throughout the seeded areas, but red clover was gradually eliminated in most places. These species have been recommended for seeding in the ESSF, ICH, IDF and SBS zones of British Columbia (Carr 1980; Mitchell and Green 1981; Utzig et al. 1983). However, data supporting this advice were not given.

Christ (1934) reported that alsike and red clovers have been commonly used on logged-over and burned ponderosa pine, Douglas-fir, and mixed conifer forestlands throughout Idaho. He pointed out that aliske clover succeeded on very moist to dry habitats, established easily and had excellent reseeding habits, while red clover generally was readily established following fire and produced well except under very arid conditions.

Sweetclover does not appear to have received much attention in British Columbia. Utzig et al. (1983) advised the use of white sweetclover in their "Dry Range" mix for drier sites in the IDF and PPBG, but did not provide or cite data demonstrating the species' suitability in these areas. Ungrazed sweetclover was found to reseed and spread throughout burned-over deciduous/coniferous forestland in the Peace River region (Anderson and Elliott 1957).

In eastern Oregon, sweetclover has been recommended as an interim forage legume on logged sites in drier zones (Berglund 1976). Christ (1934) found that on burned forestland in northern Idaho white sweetclover reseeded rapidly on arid sites and was one of the few forages tested in which the stand increased markedly over time. Well-established stands of sweetclover have been known to resist the encroachment of other vegetation for considerable periods (Christ 1934). Normally, yellow sweetclover is somewhat less winterhardy and does not produce as heavily as the white species, but because of its lower and more decumbent habit it is believed to withstand grazing pressure better than white sweetclover (Christ 1934; Martin et al. 1976). However, Evanko (1953b) observed that yellow sweetclover failed in seeding trials in northeast Washington, largely due to excessive utilization by deer and rabbits.

Alfalfa is similar to sweetclover in that it seems best-adapted to drier habitats. It has been recommended for seeding in the IDF and PPBG zones in southern British Columbia (Carr 1980; Mitchell and Green 1981; Utzig et al. 1983). Northern strains of common alfalfa are very winter-hardy (Martin et al. 1976) and, therefore, the species has also been recommended for seeding in the SBS and BWBS biogeoclimatic zone of northern British Columbia (Carr 1980). Alfalfa is generally considered to be an important forage crop although, as with clovers, there is always the possibility of bloat. Further, as the stands become older the forage tends to become quite coarse (Christ 1934).

The general consensus emerging from the literature is that legumes are relatively difficult to establish on logged and/or burned sites when compared to grasses. For example, McClure (1958) mentioned that erratic results in legume establishment on burned-over forestland in the American Northwest precluded specific recommendations for mixed seedings. Pickford and Jackman (1944) wrote that no suitable legume was available at that time for seeding burned, summer forest range in eastern Oregon. Tests with white clover had failed in their study, partly because the seed was not inoculated with *Rhizobium trifolii* (Rawsthorne et al. 1980), and partly because the shade-intolerant white clover was easily killed by the low light levels at the trial site.

In western Oregon, Dyrness (1967) experimentally hand-seeded big trefoil, white Dutch clover, New Zealand white clover, crown vetch, flat peavine, birdsfoot trefoil, cicer milkvetch and perennial vetch on an abandoned log landing. The results indicated that the white clovers and trefoils appeared to be moderately well-adapted to the site, whereas the others were not. When New Zealand white clover and big trefoil were sown with grass species in subsequent grass/legume trials along roadsides in the same vicinity, however, they both failed. Low soil moisture levels in the summer and over-winter mortality were blamed for the failure, but the addition of ammonium phosphate to the experimental plots may have given the grasses a competitive advantage over the legumes.

In yet another study carried out in Oregon, lana vetch, sainfoin, white Dutch clover and rose clover were broadcast seeded for wildlife forage on a forest burn (Anderson and Brooks 1975). Only sainfoin survived and persisted in the resulting stand.

Evanko (1953b) reported that alfalfa, burnet, alsike clover and yellow sweetclover broadcast-seeded individually in the ashes of a newly-burned lodgepole pine site in northeastern Washington all performed rather poorly. The demise of alsike clover and yellow sweetclover was partly due to heavy grazing of these species by wildlife. On cleared ponderosa pine areas in northeast Washington, milkvetch, creeping alfalfa and Ladak alfalfa seedings were all unsuccessful despite intensive seedbed preparation and planting methods (Evanko 1953a).

Klock et al. (1975) found that cicer milkvetch, birdsfoot trefoil, bramble vetch, yellow sweetclover and red clover did not emerge or died shortly after emergence when broadcast seeded on burned ponderosa pine forest in north central Washington. Sainfoin was the only legume which showed promise on this site. Unfortunately, the nitorgen-fixing properties of this species are considered poor (Tabel 13; J. D. McElgunn, pers. com.)[3].

Klock et al. (1975) stated that since the legumes were not inoculated this could have had an important negative effect on their ability to become established because soil bacteria involved in nodulation could have been killed by the fire preceding revegetation efforts (Pickford and Jackman 1944). Assuming soil bacteria were not killed, the situation was still complicated by the fact that all plots were fertilized with ammonium phosphate sulphate. The two bacterial genera *Nitrosomonas* and *Nitrobacter* oxidize ammonium to nitrate in the soil through a sequence of biochemical transformations. High concentrations of soil nitrate reduce the proportion of root hairs infected by *Rhizobium* spp. such that both the number and volume of nodules are decreased (Epstein 1972; Russell 1973). Although all seeds were inoculated in Dyrness' (1967) study, the influence of nitrate may have contributed to the poor vigour of the legumes following germination because ammonium nitrate was applied to the experimental units in order to correct nutrient deficiencies indicated by prior soil tests.

Unfortunately, the quality of legume adaptation research presented in the literature suffers from the same problems encountered in the grass species trials discussed in the previous section. These include poor experimental design, inadequate or subjective measurement, inadequate control of individual treatments and, consequently, indefinite or misleading analyses and conclusions. As well, unfavourable seasonal fluctuations in termperature and moisture often adversely influenced the outcome of many field experiments. Dyrness (1967), Klock et al. (1975) and Carr (1980) all suggest that additional study of legume germination and juvenile growth requirements on disturbed forestland is imperative, pointing out that for erosion control "the search for suitable species must be continuous" (Dyrness 1967). This holds equally true for legume species selected for forage production and grazing purposes on forest range in British Columbia.

---

[3] Director, Agric. Can. Range Research Station, Kamloops.

3.1.2.1.3 Forage Mixes

Since peak production of various forage species occurs at different times in the season, it is often desirable to combine several species in a seeding mixture. Christ (1934) pointed out that the best mixture of plants from a range point of view is one that furnishes a continuous supply of nutritious pasturage throughout the grazing season. On the other hand, Decker et al. (1973) argued that in practice early species outgrow the late ones, which are then damaged by untimely grazing. They further stated that if grazing is delayed to accommodate the requirements of late species, overall quality will be reduced. Generally, however, it is believed that a good mixture is more likely to provide a uniform supply of quality forage than a pure stand.

Other reasons suggested for seeding mixtures include (Decker et al. 1973):

1. grass/legume mixtures are usually more productive than legumes alone, and grasses contain more protein when grown with a legume;
2. mixtures resist weed encroachment better and remain productive longer than pure stands;
3. grasses added to legumes will reduce bloat when pastured.

At least 21 grass/legume mixes have been recommended for seeding landings, skidtrails and clearcuts in the Cariboo, Kamloops and Nelson Forest Regions of southern British Columbia (Appendix 8.3). Eleven of these are specifically designed for forage production and 10 are suitable for both grazing and erosion control purposes. Appropriate biogeoclimatic zones are identified for each mix and, in some cases, even specific subzones or zonal ecosystem associations. These are summarized in Table 15.

TABLE 15. Biogeoclimatic zones and subzones in southern British Columbia for which recommended grass/legume mixes have been formulated

ZONES	SUBZONES	ZONES	SUBZONES
ESSF	d, e, g, h	MS	c, d
ICH	b, e	PPBG	a, c, d, e, f
IDF	a, b, c, d	SBS	a, b, c

Certain species such as crested wheatgrass and intermediate wheatgrass appear consistently in dry country seed mixes, while other species such as timothy and orchardgrass occur frequently in mixtures intended for moister habitats. Colonial bentgrass, Kentucky bluegrass and redtop seem to be restricted to erosion control mixes whereas timothy, orchardgrass and smooth brome are primarily found in forage mixes. Perennial ryegrass (Carr 1980) and timothy (Christ 1934) often fulfill the requisite for rapidly-establishing vegetative cover in many mixes, while the need for longer-lived plants is satisfied by a variety of grasses such as smooth brome, tall fescue, intermediate wheatgrass, orchardgrass and creeping red fescue.

Although the composition of these mixes seems logical with respect to the general aim of a particular seed mixture and the ecological characteristics of component species within that mixture, few systematic and quantitative evaluations or follow-ups of past seedings have been documented in the literature. Furthermore, the rationale for including a given species in a given mix in relation to achieving the precise objectives of a given seeding program is rarely or never defined. Evidence is available indicating that seed mixes are frequently altered, depending on past experience and the availability of new varieties to test (G. Leroux, pers. com.)[4]. However, without scientific assessment of species establishment and of community dynamics in the subsequent stand, one is always uncertain whether the explicit objectives of a seeding have been accomplished.

Christ (1934) stated that choice of forage species to revegetate disturbed forestland must meet three essential qualifications in addition to adaptation to the site: (1) maximum production, (2) low cost and (3) readily available seed. He pointed out that timothy and alsike clover have been a standard combination for reseeding burned-over land in northern Idaho and provided data demonstrating the advantage of using such grass/legume mixes rather than grass alone in terms of enhanced yields (Table 16).

---

[4] Range Coordinator, Cariboo Forest Region, B.C.M.O.F.

TABLE 16. Yields of timothy, and a timothy/clover mix on burned mixed conifer forestland in Idaho (Christ 1934)

Year	Timothy (kg)	Timothy and Clover (kg)
1927	1912	3554
1928	2068	2903
1929	1125	2177
1930	853	1388
1931	544	835
Average	**1300**	**2171**

Similarly, grass sown together with alfalfa was found to consistently outyield the pure grass stand on experimentally seeded hayfields at Lacombe, Alberta (Table 17).

TABLE 17. Grass/legume vs. grass yields (kg/ha) at the Lacombe Experimental Farm, Alta. (Pharis et al. 1957)

Grass	Sown Individually	Sown with Alfalfa
Crested Wheatgrass	3721	4528
Timothy	4013	5492
Bromegrass	4708	5066

Klock et al. (1975) found that when several species were seeded as a mixture in test plots on wildfire sites in north central Washington, growth of all species was less satisfactory than when seeded singly. They attributed the poor success of the mixture to reduced seeding rates of each individual species and, possibly, competition.

Interspecific competition among constituents of a seed mix can sometimes result in a single species dominating the stand. For example, when Wilson (1969) sowed orchardgrass at amounts varying from 0 to 7.7 kg/ha along with smooth brome, creeping red fescue and white clover at a total seeding rate of 22.4 kg/ha per trial, orchardgrass comprised 50 to 70% of the herbage mixtures at all seeding rates by the second year after sowing. White clover comprised 30 to 40% of the mixture where orchardgrass was excluded, but as little as 7% where the grass was present. He concluded that the seeding rate of orchardgrass would have to be less than 1 kg/ha to maintain white clover, smooth brome and red fescue in the mix.

Similarly, perennial ryegrass was found to dominate the stand when seeded together with timothy and orchardgrass (Stapledon and Davies 1928). Wilson (1969) suggested that in situations such as these less aggressive species could be seeded at a rate high enough to produce an early ground cover, and as the aggressive species gradually developed within the community an equilibrium might be established. Alternatively, aggressive species can be avoided or, if desired for special characteristics they possess, be sown at low seeding rates as advised for redtop (Carr 1980) and perennial ryegrass (Berglund 1976).

Pickford and Jackman (1944) stated that a mixture of species is preferable in seeding programs because the chances of a complete failure are less and also because livestock seem to favour mixed forage over pure stands. However, they recommended that, in general, the mixtures used should be rather simple, pointing out that if a single species did well on a uniform site, for example, then there was little justification for incurring the additional expense of other species.

Trials by Klock et al. (1975) proved that orchardgrass, timothy, perennial ryegrass, smooth brome and tall fescue were all reasonably well-adapted for artificial seeding of firelines in north central Washington. But because of limited success with mixtures of species, they proposed that the best ground cover on these sites would probably be achieved with only one or two of these species rather than a mix of all five.

Carr (1980) indicated that erosion control seed mixes may contain from two to five grasses and one to four legumes, with the number of species ultimately chosen being dependent on soil variability and climatic severity within the specific locale to be seeded. However, he did not identify the attributes of soil and climate which promoted few or many species in a mix.

Species replacement is usually planned in a seed mix and normally involves quick cover establishment by one or two rapidly-developing, short-lived species followed by eventual domination of the plant community by slower-developing, longer-lived perennials. Slender wheatgrass, annual ryegrass, perennial ryegrass and blue wildrye have been recommended as useful species for providing expeditious ground cover, while orchardgrass, tall fescue, smooth brome, intermediate wheatgrass, crested wheatgrass and tall wheatgrass have been advocated for maintining dense vegetative cover (Carr 1980).

Carr (1980) postulated that two to three years were often required before legumes reached maturity in a grass/legume cover and were contributing nitrogen to the plant-soil system. It has been reported that supplemental nitrogen in the interim lowers the ability of legumes to compete with the gramineous component of a mix (Martin et al. 1976; Carr 1980). Therefore, if legumes are intended to comprise a significant proportion of the plant cover, the use of nitrogen fertilizers should be kept at minimum levels.

Although identical species may sometimes be present in both forage and erosion control mixes, the latter usually have a higher ratio of rhizomatous, sod-forming grasses to caespitose species. For example, the "Dry Forest" forage mix and the "Spruce-Fir" interim grazing mix in the Nelson Forest Region (Appendix 8.3) comprise three bunchgrasses (timothy, orchardgrass, tall fescue) and one mildly sod-forming grass (intermediate wheatgrass), while the "Moist Sod-Forming" mix for erosion control is composed entirely of rhizomatous species: redtop, creeping red fescue, Kentucky bluegrass and colonial bentgrass (Utzig et al. 1983).

Often a single mix is designed to accomplish both objectives. In such cases, the species selected may be biased in favour of bunchgrasses. Examples of this are provided by the "Dry Forest Mix" in southeastern British Columbia (Utzig et al. 1983) and the "Stabilization and Interim Forage" mixes on logged or burned forest in Oregon (Berglund 1976). As discussed elsewhere (Sections 3.1.2.1.1 and 3.2.1), the choice of caespitose or rhizomatous species may be of significance in formulating seed mixes compatible with tree regeneration.

3.1.2.2 Site Preparation

Historically, grass and legume seeds have been broadcast manually or aerially on burn sites, roads and landings with little or no attempt to cover the seed or precondition the seedbed (Wilson 1949; Evanko 1953b; McClure 1958; Kidd and Haupt 1968). However, it has been reported that seedings usually fail unless the soil surface is sufficiently disturbed by fire or machine to kill the existing plant populations and expose the underlying mineral soil (McLean and Bawtree 1971). Based on studies in Washington and Oregon, Gjertson (1949) stated that nearly all ground within the ponderosa pine zone that is totally denuded of vegetation by skidding, road construction or slash disposal can be successfully seeded.

On forest range it is generally not practical to make extensive use of machinery for seedbed preparation, but harrowing or shallow discing of roads and open areas before or after seeding to reduce competition from residual plants and to loosen the surface soil is often feasible (McLean and Bawtree 1971). Sage and Tierson (1975) noted from previous experience revegetating forest access roads in the state of New York that merely casting seed after dressing-up operations (e.g., covering stumps and boulders, backblading roadsides) produced unsatisfactory results. Further site preparation including liming, fertilization and harrowing was necessary for the successful establishment of a vigorous, uniformly distributed grass/legume cover.

3.1.2.2.1 Scarification

Methods for mechanically preparing cutblocks for conifer reproduction have been discussed in Section 3.1.1.2.1. One goal of such scarification treatments in timber management is to create a receptive seedbed upon which thrifty regeneration can become established and survive. However, few studies have addressed the question of seedbed requirements for grass/legume establishment in post-logging environments and whether present silvicultural techniques are adequate for both forestry and range purposes in integrated or multiple-use management.

Landings, skidtrails and logging roads generally have compacted surface and sub-surface soil horizons with decreased porosity, water permeability and infiltration. Landings represent a rather extreme form of site disturbance and remedial measures must include the elimination of slash, reduction of soil compaction and respreading of topsoil in order to re-establish a productive plant cover.

Mitchell (1982) carried out a survey of landing rehabilitation on 38 sites in the IDFb subzone and SBS zone of the Cariboo Forest Region in British Columbia. In part, he found that:

(1) there was a loss of nutrients from the site since the topsoil was removed and seldom respread;
(2) only 8% of the landings in the IDFb subzone were scarified, whereas 90% of the SBS zone landings were treated;
(3) burn piles had the greatest depth of uncompacted material and although compaction was substantially reduced at the soil surface elsewhere on the landings through scarification, compaction below the depth of scarification (10 cm) was not reduced;
(4) scarification improved the catch of grass on the 17 seeded landings in the IDFb, with best establishment and production occurring on burn piles. No grass seeding was done on landings investigated in the SBS subzones.

The survey results also revealed that shallow ripping to a depth of approximately 10 cm lessened soil compaction and improved seeding success, but because the surface tended to recompact quickly, Mitchell (1982) recommended that establishment of grass and/or trees should follow within two years of scarification. He further pointed out that since the grass catch on ash and topsoil piles was generally much better than the rest of the landing, effective spreading of these piles over the site would produce a mollified, nutrient rich seedbed without the need for scarification, given sufficient material. However, the act of spreading might add further compaction or disperse the ash too much for it to be effective.

In site preparation trials conducted on landings and skidtrails in the IDF near Williams Lake, Chernoff (1976) reported that drag scarifiers were less effective than brush blades for clearing slash and exposing mineral soil for grass seeding and natural regeneration of Douglas-fir. Unfortunately, this particular study was not of long enough duration to provide data on seeding success.

Compacted logging roads present similar challenges to forage establishment. Although no relevant British Columbia research was found, limited data were available from elsewhere in the Pacific Northwest. Kidd and Haupt (1968) studied the effects of logging road seedbed treatment on the establishment of bulbous bluegrass, crested wheatgrass, intermediate wheatgrass, smooth brome, and timothy in central Idaho. The experimental area was situated in a mixed ponderosa pine/Douglas-fir forest with coarse-textured loamy sand soils. Seedbed treatments consisted of: (1) no roadbed preparation before or after broadcast seeding; (2) scarifying to a depth of 8 cm with a spike-tooth harrow after seeding; (3) scarifying to a depth of 30 cm with a six-tooth ripper after seeding; and (4) treatment # 3 before seeding.

Comparative analysis of plant density between scarification treatments and controls revealed that (1) seeding of grass prior to deep scarification (treatment #3) was less effective than seeding alone, possibly because the ripping actions buried some seed too deeply; (2) seeding prior to harrowing (treatment #2) was not significantly different from the controls and (3) seeding immediately following deep scarification (treatment #4) was slightly better than the controls. The authors suggested that post-seeding may allow loosened soil material to slough and cover the seed and may permit surface water and seedling roots to penetrate the soil more easily. However, the data do not convincingly demonstrate the superiority of scarification treatments over broadcast seeding without any seedbed preparation, on compacted logging roads.

Approximately 5% of average clearcut blocks are occupied by landings (Mitchell 1982), and an additional 10–40% by logging roads and skidtrails, depending on the harvesting operation (Smith and Wass 1976). Most of the exposed mineral soil is found in these areas, and considerably less ground is bared through logging activity on the terrain between roads and landings. Smith and Wass (1976) estimated that roads accounted for 41.9% of the mineral soil exposed on unburned clearcuts in the Nelson Forest Region harvested by summer ground skidding operations, whereas the area between roads accounted for only 3.6% (Table 18). Disturbance between roads consisted mainly of shallow trenches compared to the deep gouges observed on roadbeds.

Table 18 summarizes further comparisons derived from this study of disturbance on and between roads within clearcuts. It is apparent that summer logging generally resulted in greater soil disturbance and hence a better seedbed than winter logging and that ground skidding denuded more surface soil than high lead logging. If the data in Table 18 can be assumed to be representative of clearcut blocks across the province, it is evident that considerable portions of these sites are unsuitable for seeding without additional site preparation. Furthermore, grazing may be intensified on the areas where a good catch occurs, thus altering animal distribution (Section 3.3.1).

TABLE 18. Comparison of mineral soil exposed on and between logging roads and skidtrails in ESSF, ICH and IDF clearcuts in the Nelson Forest Region (Smith and Wass 1976)

Logging Operation	% Mineral Soil Exposed		
	On Roads	Between Roads	Total
Ground Skidding			
Summer (unburned)	41.9	3.6	45.5
Summer (burned)	36.4	7.8	44.2
Winter (unburned)	24.5	4.7	29.2
Winter (burned)	18.8	8.2	27.0
High Lead			
Summer (unburned)	9.0	8.4	17.4
Summer (burned)	15.0	13.6	28.6
Winter (unburned)	16.4	0.5	16.9

Hoyles (1977) collected plant cover data from seeded cutblocks in the Kamloops Forest Region which, apart from site preparation treatment, were essentially similar in climatic, edaphic and floristic respects. Treatments were windrowing and burning, broadcast burning, drag scarification and no site preparation. Introduced grasses and legumes were timothy, orchardgrass, smooth brome, crested wheatgrass, white clover and red clover. The first three were most prominent in the study area when surveyed three years after seeding. When analyzed together, the average percent cover of these species was significantly greater ($0.10<p<0.15$) on the treated sites than on the untreated control (Table 19). Differences between treatments were not demonstrated in this study.

TABLE 19. Average percent cover of the three most prominent seeded grasses on lodgepole pine clearcuts near Kamloops, B.C., treated by windrowing and burning, broadcast burning, drag scarification and no site preparation (data from Hoyles 1977)

Species	Windrowed, Burned	Broadcast Burned	Drag Scarified	No Treatment
Smooth broome	3.0	2.6	3.7	0.5
Orchardgrass	3.2	3.8	1.3	0.2
Timothy	1.3	0.5	0.2	0.2
Total	**7.5**	**6.9**	**5.2**	**0.9**

3.1.2.2.2 Prescribed Burning

Successful seedings have often been obtained on wildfire burns in the Pacific Northwest (Wilson 1949; Anderson and Elliott 1957; Anderson and Brooks 1975). Pickford and Jackman (1944) postulated that such successes were related to the excellent seedbed characteristics of ash-covered ground. They pointed out that the broadcast seeds sank into the ashes and, if moisture was present, conditions for germination were almost ideal. However, it was stressed by these authors that seeding should take place soon after the burn since rainfall crusted the ash layer and quickly destroyed the quality of the seedbed (Pickford and Jackman 1944; Anderson and Brooks 1975).

The ash is believed to be rich in certain mineral elements released from burned organic matter and consequently could be important as a short-term reservoir of plant nutrients. On the other hand, Daubenmire (1968a) argued that the fertility following a fire was immediately made available at the soil surface where it was subject to horizontal displacement by wind or water. The minerals were also susceptible to loss by rapidly leaching through the soil profile before they could be adsorbed on colloids or taken up by soil organisms (Daubenmire 1968a).

The properties of wildfires are duplicated to some extent by broadcast burning, although fuel loads can be somewhat more concentrated than normal in areas of slash accumulation (Smith 1962). In the Cariboo region of British Columbia, Mitchell (1982) observed that burnpiles on landings produced the best grass catches and supported the most production per unit area when seeded to domestic species. In the Kamloops Forest Region, Hoyles (1977) found that average percent cover of timothy, orchardgrass and smooth brome was 7.5% on windrowed and burned sites, 6.9% on broadcast burns, and 5.2% on drag scarified sites three years after seeding (Table 19). However, these differences were not statistically significant.

McClure (1958) postulated that the initial heavy production of grasses the first year after seeding on forest burns was partly due to available nitrogen liberated to the soil at the time of burning. Some support for this hypothesis has been given by Vlamis et al. (1955) who examined the effect of prescribed burning on the "nitrogen supplying power" of two ponderosa pine forest soils in California. Soils subjected to a heavy burn showed an increased nitrogen supply over lightly burned soils, and the latter had more nitrogen than unburned soils.

In contrast, other researchers have reported nitrogen losses through volatilization after fires (Daubenmire 1968a). Anderson and Elliott (1975) found that soils on burned-over deciduous/coniferous forestland in northern British Columbia and Alberta were low in organic matter, and seeded timothy, crested wheatgrass, creeping red fescue, smooth brome and Kentucky bluegrass showed signs of nitrogen deficiency except where legumes were present. Ahlgren and Ahlgren (1960) attributed contradictory reports in the literature concerning increased or decreased nitrogen after a fire to the stimulation or inhibition of soil and nodule bacteria and soil fungi as they responded to changes in soil conditions caused by the fire.

Soil temperatures are higher and soil moisture somewhat lower on burned forest range than unburned (Beaton 1959; Tarrant 1956). It is uncertain how important these factors are in influencing plant establishment and growth on burn sites because no autecological studies specifically addressing this topic were found in the literature. A further concern is the difficulty in establishing large-seeded species on burned soils. Christ (1934) stated that it was possible to obtain a good stand of large-seeded species much more readily under cultivated conditions than under the conditions that prevailed after a fire. He suggested that lack of seed coverage was probably why these species were not more successful in seeding trials on burned-over land in northern Idaho.

3.1.2.2.3 Fertilization

Fertilizer applications may sometimes accompany seeding operations to improve the establishment of introduced species (Bethlahmy 1960; Jackman and Stoneman 1973; Sage and Tierson 1975). Decker et al. (1973) reported that although high levels of nitrogen, phosphorus and potassium were desirable in establishing forage crops under agronomic conditions, phosphorus levels were most critical.

Little quantitative data examining the effects of fertilization on forage seedings were found in the British Columbia literature. In the MS zone of southern British Columbia, Clark and McLean (1975) noted that high rates of N and S increased yields of timothy, orchardgrass, smooth brome and crested wheatgrass on seeded lodgepole pine clearcuts. Herbage yields on fertilized plots were greater than 5000 kg/ha, while unfertilized contols were less than 2000 kg/ha after one year. However, the effects of fertilization had diminished substantially by the end of the second growing season (Clark and McLean 1979).

Elsewhere in the Pacific Northwest, Bethlahmy (1960) found that fertilizing an abandoned logging road in an Oregon old-growth Douglas-fir forest with 505 kg/ha of 6:10:4 (N:P:K) fertilizer greatly increased the number of stems per unit area of tall oatgrass, alta fescue, perennial ryegrass, alsike clover and white clover. Average stem density was almost 40% higher on fertilized treatment plots compared to controls (Bethlahmy 1960).

Kidd and Haupt (1968) reported that two years following application of 45 kg/ha each of N and P fertilizers to a logging road in an Idaho ponderosa pine/Douglas-fir forest, density of seeded domestic herbs was not significantly increased. It is possible that the available nutrients in the small amount of fertilizer used in this study had leached out of the soil by the second growing season, resulting in the insignificant difference in vegetative growth between fertilized and unfertilized plots.

Geist (1976) demonstrated in laboratory trials that N and soluble S additions to volcanic ash soil should effectively aid rapid establishment of orchardgrass from seed on eastern Oregon landings, skidtrails and cutting areas. He suggested that the rapid early growth takes optimum advantage of stored soil moisture prior to onset of the dry summers which typically occur throughout much of the northwest. Similar results were reported by Pumphrey (1971) in which intermediate wheatgrass, big bluegrass, bromegrass, tall oatgrass and meadow foxtail fertilized with N, P and S produced high forage yields in field trials on volcanic ash soils cleared of forest in northeastern Oregon.

Carr (1980) pointed out that the exposed soil or surficial matter of the forest floor was typically acidic, often possessing pH values prohibitive to successful legume establishment and restrictive to uptake of esssential soil nutrients by grasses. It has been suggested that soils with pH 6 or less should be limed prior to sowing seed (Sage and Tierson 1975).

Carr (1980) stated that fertilizer addition of nitrogen, phosphorus, potassium and possibly sulphur was frequently required for erosion control seedings on logging roadsides in British Columbia to ensure satisfactory establishment. He added that nutrients initially introduced to the soil system were usually tied-up in plant biomass within two years and refertilization in the second and fourth years was advisable for continued vigour of the plant cover. However, experimental evidence was not cited to support these recommendations.

High levels of nitrogen fertilization, which are frequently beneficial for grass establishment, may hinder legume establishment (Carr 1980). The additional nitrogen has been known to lower the ability of legumes to compete with the grasses and depress N-fixation (Woodhouse and Griffith 1973). This phenomenon could possibly have been operating in a recent study by Clark and McLean (1979). These researchers noted that alsike clover populations almost doubled their percent contribution to total yield on unfertilized control plots compared to N-fertilized test plots in grass/legume seeding trials on a burned forest site near Kamloops, B.C.

Similarly, conifer seedlings may be unable to compete with fertilized grasses, an important consideration in multiple-use situations. For example, in British Columbia Clark and McLean (1979) observed that significantly fewer lodgepole pine seedlings survived on areas sown to grass and treated with N and S fertilizer than on unseeded, untreated control plots. However, there were no statistically meaningful differences in seedling weight or height among all treatments, including the control (Clark and McLean 1979).

Crouch and Radwan (1981) found that when Douglas-fir seedlings in Washington were fertilized with N and P, native velvetgrass responded dramatically and was suspected of competing strongly with the young trees. However, proof of this was unavailable. In northern Mississippi, Duffy (1974) noted that seeded lovegrass fertilized with N, P and K significantly depressed development of planted loblolly pine seedlings. Likewise, fertilizer-stimulated production of bluegrass was found to significantly decrease height growth of associated radiata pine in experiments in northeastern Victoria, Australia (Squire 1977).

3.1.2.3 Seeding Forage Mixes

The probability of successfully establishing a seeded forage cover may be increased by sowing the mix during the time of year best suited to the germination requirements of its constituent species. Similarly, the seeding rates of individual species within a mixture determine in large measure the outcome of a seeding operation. This holds equally well for the seeding rate of a species mix when considered as a single entity.

3.1.2.3.1 Time of Seeding

The timing of a seeding operation on disturbed forestland depends on a number of factors (Christ 1934; Gjertson 1949; Kidd and Haupt 1968; McLean and Bawtree 1971), including:

1. (1) species composition of the seed mix;
2. (2) season in which the disturbance occurred;
3. (3) period of most favourable soil moisture conditions;
4. (4) likelihood of summer drought;
5. (5) timing of reforestation activities.

Since some species are more suited to fall planting and others to spring planting (Evanko 1953a), the germination and juvenile establishment requirements of the grasses and legumes comprising a mix are of considerable relevance in deciding when to seed. Several authorities recommend that areas disturbed in the winter and early spring should be seeded in the spring, while those disturbed over summer and autumn should be seeded in late fall (Gjertson 1949; Rummell and Holscher 1955).

Climatic characteristics and soil moisture retention capacity of a site are important factors to consider since spring seedings often fail in areas with a propensity for summer drought (Kidd and Haupt 1968). Where trees and forage are grown together, the timing of a seeding operation relative to reforestation can be critical in determining the success or failure of integrated multiple-resource use (Clark and McLean 1978).

Few published studies were found which directly investigated this topic in British Columbia. In the BWBS zone, Anderson and Elliott (1957) observed that seeding time did not influence the establishment of crested wheatgrass, creeping red fescue, smooth brome, Kentucky bluegrass or timothy on burned coniferous/deciduous forestland. However, alfalfa, alsike clover, red clover and sweetclover established themselves more readily when sown in April rather than October (Anderson and Elliott 1957). Pringle and McLean (1962) presented guidelines for seeding forest ranges in the dry belt of British Columbia. They recommended seeding grasses and legumes before September so that the seedlings could become established before severe frost.

Carr (1980) stated that both spring and fall seedings for logging roadside erosion control in British Columbia could be successful if proper precautions were followed. He pointed out that established seedlings should be at least six to eight weeks old before being exposed to drought or frost. Since prediction of future weather events is unreliable, he recommended the inclusion of species suited to both spring and fall sowing in the mix. Unfortunately, this is a rather unscientific and inefficient approach to the problem of when to seed. The seed mixes thus derived cannot be considered an integrated group of compatible species, but merely an aggregation of species which collectively are adapted to a wide range of environmental and germination conditions

General guidelines for seeding forest rangelands in the PPBG, IDF and ESSF biogeoclimatic zones of southern British Columbia were given by McLean and Bawtree (1971). They advised seeding forage plants as soon as possible after disturbance to take full advantage of the exposed mineral soil and to establish the introduced species before weeds invaded the site. However, Clark and McLean (1978) argued that despite the need to sow grass when the seedbed is new and fresh, seeding more than one year in advance of restocking a clearcut with trees through artificial or natural methods may result in serious competition between established forage plants and tree seedlings (Section 3.2.1).

Studies in the American Pacific Northwest generally support the belief that late fall is the best time of year to seed logged sites, especially after summer logging operations which create considerable soil distrubance. Successful seeding of grass/legume mixtures has occurred from late September to mid-December in Idaho (Kidd and Haupt 1968), Oregon (Wilson 1949; Dyrness 1967; Anderson and Brooks 1975; Helvey and Fowler 1979) and Washington (Evanko 1953b; McClure 1958) on a diversity of sites. In late fall the soil surface is fairly rough and loose, and low temperatures do not permit germination until spring (Gjertson 1949). Winter precipitation usually provides sufficient spring moisture for germination and growth.

Kidd and Haupt (1968) pointed out that spring seedings in the ponderosa pine areas east of the Cascades in Oregon and Washington generally resulted in failure. This was believed to be due to poorly-developed root systems on the newly-germinated seedlings which reduced juvenile survival during the hot, dry summers characteristic of the region (Kidd and Haupt 1968; Geist 1976). The accepted practice in these areas has therefore been to broadcast seed late in the fall.

Christ (1934) remarked that time of seeding was apparently not a decisive factor in obtaining forage stands on burned forest sites in Idaho provided there was an ample supply of moisture. However, he qualified this statement by adding that fall seedings were desirable because rainfall in September and early October was normally sufficient to create a moisture contact between the surface and subsurface soil layers. Where this occurred, loss of germinating plants was unlikely (Christ 1934).

In fall seedings, early freeze-up after plants have germinated may result in extensive mortality (Christ 1934; Gjertson 1949; Wilson 1949). For example, Evanko (1953a) compared spring versus fall plantings of 30 different forage species on abandoned ponderosa pine areas in northeastern Washington. Based on fall 1950 and spring 1951 seedings, plant vigour was better in the fall plantings. However, a comparison of seedings in the fall of 1951 and spring of 1952 showed striking differences in favour of spring sowing. Evanko (1953a) attributed the unsatisfactory performance of the 1951 fall planting to prolonged below-freezing temperatures that year before the soil was protected by snowcover.

Seed is sometimes broadcast directly onto the snow in early spring with the intent that germination will occur as soon as soil moisture and temperature conditions become favourable. For example, Orr (1970) aerially seeded a snow-covered forest burn in the Black Hills of South Dakota in April. However, the ensuing vegetative cover in this study was quite irregular because runoff and soil erosion caused seed displacement and loss. Redistribution of seed also occurs if the snow is crusted and seeds are blown along the surface (McLean and Bawtree 1971). A further disadvantage of broadcasting seed onto snow is determining whether the soil surface under the snowcover is appropriate for seeding. Given time and manpower, however, the site can be surveyed before snowfall and suitable areas demarcated.

Of the grasses tested in Evanko's (1953a) study in Washington, orchardgrass and four species of wheatgrass (beardless bluebunch, crested, intermediate, pubescent) produced successful stands in the two spring plantings. Smooth brome, tall fescue and hard fescue also produced reasonably satisfactory stands during the spring seedings, while timothy, mountain brome, Idaho fescue and three bluegrass species were disappointing in all respects. Outstanding grasses in the fall of 1950 included the most successful of the spring-planted species as well as tall, sheep and hard fescues and timothy. The following year, however, these species all performed quite poorly.

Identifying the best season for seeding legumes is confounded by the difficulty in finding species adapted to disturbed forest sites. Dyrness (1967) reported that in most cases germination and growth of several species of clover, vetch and trefoil showed little difference between spring and fall seeding in the Coast Ranges and western Cascades of Oregon. However, his study sites were not representative of interior biogeoclimatic conditions in British Columbia. Anderson and Elliott (1957) observed that percent ground cover of spring-seeded alfalfa, alsike clover, red clover and sweetclover was greater than that of autumn-seeded legumes on burns in northern B.C., while Evanko (1953a) found that alfalfa did poorly in both spring and fall seedings on abandoned ponderosa pine land in northeast Washington.

3.1.2.3.2 Rate of Seeding

Seeding rates are influenced by seed size, seed quality, pure live seed ratio, species composition of a mix, environmental conditions and management objectives (Christ 1934; Carr 1980). Rates of application are conventionally determined as seed weight per unit area. This is convenient for operational procedures, but since the intent of seeding is to establish numbers of individual plants on the ground, rates should logically be discussed in terms of number of seeds per unit area. Likewise, seeding success should be measured as the resultant plant population density in numbers per unit area compared to the actual number of seeds sown for that species.

Given that relationships exist between weight and number of seeds for most forage species (Smoliak et al. 1981b), conversion of rates from weight to numbers per unit area is straightforward. However, since the literature reports seeding rates on a weight/unit area basis, they are treated the same way in this review.

Seeding success is normally measured as degree of plant cover, vigour or production on a per species or total vegetation basis. No experimentally-derived information relating forage seeding rate to seeding success on disturbed forest sites was found in the British Columbia literature. However, a number of published guidelines offer recommended seeding rates for specific environments, objectives and seed mixes.

Pringle and McLean (1962) and McLean and Bawtree (1971) advised rates of 6–9 kg/ha depending on seedbed and moisture conditions for forest rangeland seeding in southern British Columbia. In the Kamloops Forest Region, Mitchell and Green (1981) suggested 7 kg/ha for seeding the dry IDFa, IDFb and PPBG subzones, but only 3–3.5 kg/ha in the wetter MSc. Similarly, Utzig et al. (1983) recommended forage seeding rates of 6–10 kg/ha in the IDF and PPBG zones of the Nelson Forest Region, and 4–6 kg/ha in the moister ICH, ESSF and MS.

Carr (1980) remarked that dry areas in the British Columbia interior may be broadcast seeded at 20 to 30 kg/ha for erosion control. He stated that the rate of seed application was generally much higher for erosion control than for range or agronomic purposes because the primary objective of the former is to establish a dense vegetative cover quickly. He further pointed out that since higher seed loss and seedling mortality was expected with broadcast seed application in comparison with seed drilling, broadcast seeding rates were often double that recommended for drilling.

Similar seeding guidelines and recommendations were noted outside British Columbia. Burned and logged sites were usually seeded by manual or aerial broadcasting since there was generally too much debris to permit seed drilling (Pickford and Jackman 1944). Rates were frequently much higher for erosion control than for forage seedings.

Forage seedings in the American Pacific Northwest have historically been sown at low rates primarily because these programs were carried out on private land at the owner's expense. Thus, most farmers were content to make lighter seedings to establish the forage and check the ingress of weedy species, relying on time to thicken the grass stands (Christ 1934). Gjertson (1949) recommended 9–11 kg/ha, including 0.5 kg of timothy and 1 kg of orchardgrass, for seeding forage on logged areas of Washington and Oregon. Christ (1934) proposed 11–17 kg/ha on burned-over land in northern Idaho for obtaining pasturage quickly, while Pickford and Jackman (1944) suggested that a rate of 6 kg/ha should suffice for recent burns in Oregon.

Higher seeding rates have been used for erosion control. Dyrness (1967) sowed four different grass/legume mixtures comprised of varying amounts of colonial bentgrass, creeping red fescue, perennial ryegrass, tall fescue, Chewing's fescue, Italian ryegrass, orchardgrass, white clover and big trefoil at rates ranging from 28 to 50 kg/ha for erosion control on logging roadbeds in Oregon. Kidd and Haupt (1968) seeded 40 kg/ha of winter rye, crested and intermediate wheatgrass, smooth brome, timothy and bulbous bluegrass on comparable sites for the same purpose in central Idaho. Greater than half, by weight, of Kidd and Haupt's mixture was comprised of winter rye, a species which is sown at high rates to provide a quick, yet transitory ground cover prior to slower establishment of cultivated or native perennials. Annual ryegrass is often seeded at high rates for the same purpose (Jackman and Stoneman 1973).

Erosion control seedings on burns appear to use somewhat lower seeding rates than on skidtrails and logging roads. Anderson and Brooks (1975) seeded a mix of crested and intermediate wheatgrass, big bluegrass, timothy, hard fescue and orchardgrass at a rate of 11 kg/ha on a burned pine/mixed fir forest in Oregon. Orr (1970) seeded 12 kg/ha of timothy, smooth brome, Kentucky bluegrass, yellow sweetclover and hairy vetch on a ponderosa pine burn in the Black Hills of South Dakota. Seven to 10 kg/ha of orchardgrass, hard fescue, timothy and sweetclover were seeded for erosion control in a rehabilitation project in northcentral Washington following a forest fire (Klock et al. 1975).

Higher rates are used when seed quality is poor. For example, Wilson (1949) sowed several mixtures composed primarily of crested and slender wheatgrass, tall oatgrass, perennial ryegrass, smooth brome, timothy, alfalfa and sweetclover at rates varying from 18 to 25 kg/ha on a ponderosa pine burn in Oregon. The seed had been in storage for several years, with average germination reduced to approximately 35%, so sufficient seed was used to give a rate equivalent to 9 kg of good seed per hectare. At the other extreme, Helvey and Fowler (1979) experimentally seeded a mix of hard fescue, intermediate wheatgrass, orchardgrass and white clover for erosion control at a rate of only 4 kg/ha on a burned clearcut in northeastern Oregon. Despite this low seeding rate, 46% of the ground surface in the seeded area was covered by introduced species when sampled after two growing seasons, with an additional 10% occupied by native herbs and shrubs.

Seeding rates are also affected by the species composition of the seed mix since the number of seeds per kg varies immensely among species depending on seed size. For example, small-seeded timothy has approximately 2,710,000 seeds/kg, while large-seeded smooth brome contains roughly 300,000 seeds/kg (Smoliak et al. 1981b). Christ (1934) suggested that for mixed forage seedings the rate should be reduced to two-thirds the amount used for each species in pure stands, although the rationale for this recommendation was not defined. It is essential that differences in competitiveness be taken into account when determining seeding rates for individual species within a mix, as in the case of perennial ryegrass discussed earlier (Section 3.1.2.1.1).

Low seeding rates have been advised in situations where forage grasses and juvenile tree seedlings are likely to interact competitively. In southern British Columbia, for example, Clark and McLean (1978) recommended that lighter rates than the usual 4.5 kg/ha for grass seeding be used to reduce early competition with tree seedlings since most grass stands increased in density during the first three years after seeding. These results apply explicitly to orchardgrass, timothy, smooth brome and crested wheatgrass in the IDF and MS biogeoclimatic zones. Unfortunately, the experimental results were partially confounded by climatic conditions which adversely affected germination, survival and growth of grass and naturally regenerated tree seedlings on many research sites at the beginning of the study (Clark and McLean 1974; 1978). More research into this problem seems appropriate, although the findings of Clark and McLean (1975; 1978; 1979) provide valuable benchmark data against which additional study may be assessed.

3.1.3 Summary and Discussion

Following clearcut logging, management objectives may include the simultaneous establishment of trees and domestic forages on the disturbed site to accommodate both forestry and grazing interests. Restocking of conifers may occur naturally from local seed sources, or artificially through planting or direct seeding. Introduction of domestic grasses and legumes involves broadcast seeding, either aerially or manually.

Tree species commonly regenerated naturally or artificially on harvested forest range in British Columbia include lodgepole pine (ESSF, ICH, IDF, MS, SBS), Douglas-fir (ICH, IDF, MS, PPBG), Engelmann spruce (ESSF, ICH, MS, SBS), white spruce (BWBS, SBS, SWB) and subalpine fir (ESSF, ICH, MS, SBS). Ponderosa pine is locally important in the PPBG and IDF zones in the southern part of the province.

Lodgepole pine is widely distributed throughout the entire province. White spruce is most common in the northern regions, but may also occur at lower elevations in the south. Engelmann spruce is generally found in subalpine areas of the southern interior. Hybridization of white and Engelmann spruce is a common occurrence, particularly in the SBS zone where the ranges of the two species overlap. Subalpine fir occurs at high elevations across British Columbia.

Selection of conifer species for regeneration in post-harvest plant communities depends largely on adaptation to the physical conditions of the site. This adaptation is first manifested in appropriate germination and juvenile growth requirements.

Germination of lodgepole pine, Engelmann spruce, white spruce and subalpine fir is best on mineral soil. Douglas-fir germinates most successfully on a shallow litter layer overlying mineral soil. Establishment and early survival of Engelmann spruce, white spruce and Douglas-fir is improved by partial shade, while subalpine fir is favoured by deep shade. Lodgepole pine is shade-intolerant.

At the present time it is unknown whether differences exist among these tree species in their ability to survive and withstand trampling or browsing damage by cattle or competitive interactions with seeded grasses and legumes. Clearly, if such differences can be demonstrated through carefully designed and executed experimentation then this factor should be included in the criteria for selecting tree species for regeneration on forest range. Research is required in this area.

The physical conditions of a site can be modified and made more amenable to seeding or planting needs by mechanical site preparation or prescribed burning. Drag scarification is the usual method of seedbed preparation for natural regeneration of lodgepole pine, while blade scarification is often employed prior to planting spruce. Broadcast burning, the most frequently used of the prescribed burning techniques, serves as an alternative means of site treatment for planting spruce. Bunching and burning is important in seedbed preparation for natural regeneration of commercial conifers.

The method, equipment and intensity of post-harvest treatment is dictated by: (1) slash and fuel loads, (2) topography, (3) presence of serotinous cones, (4) depth and compactness of the humus layers and (5) the degree of site preparation required for silvicultural purposes. Thus, the germination and establishment requirements of the regenerating tree species are only some of the criteria used in determining which method of treatment to apply on a given site. In general, however, it seems that mineral soil exposed by scarification is superior to burned soil as a seedbed for white spruce, lodgepole pine and Douglas-fir.

The forage grasses which appear to have been most frequently sown, either operationally or experimentally, on harvested forest range throughout the Pacific Northwest are timothy, orchardgrass, smooth brome and crested wheatgrass. Timothy and orchardgrass have been quite successful in broadcast seedings because their small seeds withstand minimal soil coverage. On the other hand, some difficulty has been experienced in broadcasting smooth brome and crested wheatgrass on disturbed forest soils because their larger seeds often do not become sufficiently covered and the subsequent germinants are susceptible to drought and heat-induced mortality. As well, there is the possibility of seed losses to small mammals and birds.

Although numerous other species have been sown or recommended for sowing in such environments, justification for their use has been mainly derived from experience and casual observation rather than controlled experimental research. Furthermore, most of the available literature on this subject is restricted to the PPBG and IDF biogeoclimatic zones, with very little quantitative information concerning the BWBS, ESSF, ICH, MS and SBS. Varietal trials to identify suitable domestic grasses for seeding on clearcuts and burns in these zones, particularly in the northern part of the province, are clearly needed. Since these zones are located at higher elevations and latitudes, the emphasis in such seeding trials should be on extension of the grazing season.

White clover, alsike clover, yellow and white sweetclover, red clover and alfalfa are legume species which have been seeded most often on disturbed forestland in the Pacific Northwest. However, the general consensus emerging from the literature is that legumes are more difficult to establish on these sites than grasses. Again, most of the available information is pertinent only to the PPBG and IDF zones. Varietal trails are required to assess the adaptability of various legumes to the climatic and edaphic characteristics of biogeoclimatic zones in the higher elevations and northern regions of the province.

One of the major reasons for seeding legumes has been to increase the supply of soil nitrogen on the site. However, this has not been thoroughly investigated on harvested or burned forest range. Quantitative data are needed to evaluate the significance of the legume contribution to total soil nitrogen on impoverished sites, and to determine the degree to which this management objective is being achieved.

A number of grass/legume mixes have been formulated for seeding landings, skidtrails and clearcuts in several biogeoclimatic zones throughout southern British Columbia. However, the rationale for these particular species mixes has not been defined. Furthermore, systematic and quantitative follow-up of past seedings with these mixes has not been undertaken. Without scientific assessment of species establishment and ecological interrelationships such as competition within the subsequent plant community, one is uncertain whether the predetermined goals of the seeding have been accomplished. Thus, it is recommended that in future seeding programs, both operational and experimental, the germination, establishment, population density, distribution and mortality of the sown species should be monitored periodically over the succeeding years to determine the efficacy of the seeding mix.

Very little information has been published on the type of site treatment or seedbed preparation required for successful establishment of seeded grasses and legumes in post-logging environments. Assuming introduced species are adapted to the habitat, the amount of exposed mineral soil present on the site will most likely determine their success or failure. Broadcast seed which falls on undisturbed duff or residual vegetation usually perishes.

Germination of both trees and domestic grasses and legumes is generally improved on a mineral soil seedbed. However, additional research is necessary to determine (1) which site attributes contribute to, and (2) what degree of mineral soil exposure is required for, satisfactory and compatible establishment of coniferous regeneration and aerially-seeded domestic forages on B.C. clearcuts. Further, the effect of fertilizers on tree/grass establishment, production and competition should also be investigated.

Late fall has generally been advocated as the best time of year to seed in the American Pacific Northwest. However, experimental studies concerned with season of seeding have produced inconsistent and variable results. It is usually agreed that seeding should occur as soon as possible in the spring or fall after disturbance to take advantage of the exposed mineral soil and to establish the introduced species before weeds or brush enter the site. But despite the need to sow when the seedbed is fresh, it has been argued that seeding more than one year prior to restocking a clearcut with conifers may result in competition between grass and tree seedlings. Given that such competition does indeed occur, however, long-term effects of this interaction have yet to be quantified.

Likewise, recommended and operational seeding rates have been variable in the literature. They are influenced by seed size and quality, species composition, environmental conditions and management objectives. Rates are generally higher for erosion control than for forage seedings because a quick, dense vegetative cover is the primary aim of the former. Within a mix, seeding rates of the constituent species are largely determined on the basis of interspecific differences in seed size, but the competitiveness of the species should also be taken into account. To reduce competition with trees, lower seeding rates than usual for broadcast forage seedings have been recommended.

Despite the existence of numerous published guidelines advising specific seeding times and rates for grass/legume establishment in various habitats and for different management purposes, sampling programs should be implemented to monitor subsequent stand development systematically over time. Such post-seeding evaluations should be based upon forage quality and productivity in relation to time of seeding (spring versus fall), seeding rates and the establishment of individual species, with the ultimate goal of refining the composition and application of the seed mix to achieve optimum results.

Perhaps the most fundamental factor to consider when selecting grass species for forage on multiple-use forest range is the question of compatibility with conifer seedlings. Although several relevant studies have been reported, there is still considerable scope for additional research, particularly with tree species other than lodgepole or ponderosa pine, and in biogeoclimatic zones other than the IDF, PPBG and MS in southern British Columbia. This research should identify compatible grass/legume species and determine their optimum seeding rates to reduce competition with such conifers as Englemann and white spruce, Douglas-fir and subalpine fir. Similarly, the longterm relationships between time of sowing, tree growth and herbage production on different range sites with different conifer and domestic forage species requires investigation. Coupled with these recommendations is the need to verify the applicability of zonal/subzonal seed mixes based on the B.C. Ministry of Forests ecological classification guidelines, with respect to producing satisfactory forage stands and minimizing negative interactions with conifer regeneration on different range sites within given biogeoclimatic zones or subzones.

3.2 Synecology of Post-Harvest Forest Communities

Successional development within seeded burns and clearcuts involves dynamic interactions among seeded or planted trees, introduced forage grasses and legumes, and native herbs and shrubs. The population density and distribution of any single species over time is determined to a large extent by the competitive pressure exerted by other members of the plant community. Areas of concern to resource managers include (1) competition among tree seedlings, domestic grasses and native vegetation, (2) the fate and persistence of seeded forages, and (3) the rate of recolonization and development of native plants.

3.2.1 Tree/Forage Interactions

Plants co-existing in the same habitat may interact with each other negatively through competition or allelopathic interference. Competition occurs when two or more plants require a particular environmental factor such as water, nutrients, light, oxygen, or carbon dioxide whose available supply is less than the combined demand of the organisms (Risser 1969). Adaptations which, under specific circumstances, may help plants cope with the environmental complex in a competitive situation include: (1) rapid root penetration; (2) ability to obtain nutrients in short supply and to take up moisture against tensions greater than the wilting point; (3) endurance in drought or on soils with poor aeration; (4) longevity; (5) abundant seed production and efficient seed dissemination; (6) abundant food reserves available to young plants; (7) early initial growth; (8) rapid rate of growth; (9) vegetative reproduction; (10) ability to grow at low soil temperatures; (11) genetic variability; and (12) phenological/physiological plasticity (Daubenmire 1968b).

In southern British Columbia, Clark and McLean (1975; 1979) examined the growth of lodgepole pine in competition with seeded grasses. Under controlled growth-room conditions they observed that decreased frequency of water and increased density of orchardgrass significantly reduced survival, height growth and biomass of lodgepole pine (Clark and McLean 1975). In a later study, lodgepole pine was grown with orchardgrass, timothy, smooth brome, red fescue, hard fescue and crested wheatgrass, all sown individually on separate field plots (Clark and McLean 1979). No apparent or statistically significant harmful effects were observed on establishment, survival or growth of pine seedlings from any of these grass species.

Clark and McLean (1979) postulated that high rates of nitrogen addition may produce high grass yields which could inhibit the development of conifers. In their study, negative impacts were noted on tree seedling survival the first year following fertilization. Mortality was significantly greater on fertilized than unfertilized plots. High forage yields were initially correlated with high rates of N application, but grass productivity in subsequent years did not differ between fertilized and unfertilized plots. Interestingly, the weight and height of those tree seedlings surviving in the fertilized treatment plots were not significantly different from seedlings in the controls (Clark and McLean 1979).

In northcentral British Columbia, Eis (1981) studied competition between planted white spruce and native vegetation on cutblocks within the Alluvium forest-site type described by Illingworth and Arlidge (1960). This site type is believed to have high potential as native range (Pojar et al. 1982). Over the first two years of study following logging, native graminoids such as bluejoint reedgrass, slimstem reedgrass, nodding woodreed and beaked sedge increased in cover from 7 to 30%, mostly on compacted roads, landings and skidtrails. Eis (1981) pointed out that although competition from these and other herbs probably slowed down the rate of growth of spruce seedlings for a few years, it rarely caused significant mortality or failure of spruce regeneration.

During the same period shrub cover increased from 16% to more than 50% (Eis 1981). By the third year, competition between conifer seedlings and shrubs was so intense that on plots where the latter were not annually removed, height growth of regenerating white spruce was usually less than 2 cm and mortality was severe.

Outside of British Columbia, considerably more published research is available investigating interactions between herbaceous plants and tree seedlings. Most authors agree that competition for soil moisture is perhaps the major ecological factor in these interactions.

3.2.1.1 Competition for Soil Moisture

McClure (1958) stated that seed source and climatic conditions were the primary agents influencing forest regeneration in the Pacific Northwest, with the competitive effect of perennial grass cover subordinate to and modified by the impact of these two influences. However, soil moisture is often limiting on harvested forest sites, and competition between tree regeneration and seeded grasses for this resource can sometimes be quite severe (Rindt 1965).

Adequate moisture is essential for the successful establishment of conifers. The amount and distribution of water has been shown to affect the germination, survival and growth of ponderosa pine (Noble et al. 1979), lodgepole pine (Shepperd and Noble 1976), and Douglas-fir (Noble et al. 1978).

Baer et al. (1977) found that watering, shading and size of stock had no significant effect on survival of planted lodgepole pine during a summer with above-average precipitation in north central Wyoming. However, in a summer with below-normal precipitation, shading increased survival significantly by reducing water loss from the soil surface and by decreasing seedling transpiration (Baer et al. 1977).

Noble and Ronco (1978) observed that newly germinated seedlings of Englemann spruce in Colorado clearcuts, particularly those on south and west-facing slopes, had to be protected from excessive insolation and moisture loss with a cover of slash or other material to ensure survival. Strothman (1972) showed that simply shading Douglas-fir in northern California did not significantly improve the survival of planted stock, but did increase the establishment of seedlings.

Rindt (1965) pointed out that ponderosa pine seedlings were less resistant to drought than many grasses and other associated vegetation, and hence could not survive in competitive interaction until sufficient root development had occurred below the zone of moisture stress. Lane and McComb (1948) remarked that perennial grasses generally withstood drought and outcompeted tree seedlings by the faculty of their extensive roots and rhizomes to become temporarily dormant under adverse conditions, starting growth again as soon as soil moisture was available. On the other hand, tree seedlings became progressively more desiccated until all parts died (Lane and McComb 1948).

First year seedlings were especially vulnerable. Noble (1973; 1979) found that roots of Engelmann spruce and lodgepole pine reached depths of only 8 to 10 cm in their first season of growth. Arnold (1950) stated that young ponderosa pine seedlings apparently overcame herbaceous root competition for soil moisture after only five years on Arizona forest range, but Basile and Jensen (1971) conservatively estimated that roots of lodgepole pine seedlings on Montana clearcuts required about ten years to gain a competitive advantage over herbaceous plants for available moisture.

An early study by Lane and McComb (1948) revealed that smooth bromegrass absorbed soil moisture more rapidly than black locust or green ash. Further, the permanent wilting coefficient, calculated as a percentage of oven-dry weight, was lower for brome than for the two deciduous trees (Lane and McComb 1948).

Sims and Mueller-Dombois (1968) performed an elaborate experiment in which jack pine, red pine, white spruce and black spruce seedlings were grown with junegrass, bluejoint, and big bluestem on loamy sand and sand soil types with simulated soil moisture gradients. At optimum depth to the water table on the loamy sand, where maximum height growth for tree seedlings had occurred in a previous study without grass competition (Mueller-Dombois 1964), the grasses grew more vigorously and suppressed the conifer seedlings. On the sandy soil, grass production was considerably less than on loamy sand, and tree seedling height trends were not significantly altered from those observed without competition. These results suggested that seedling growth on the latter soil type may be determined chiefly by physical factors such as soil texture and water retention capacity rather than by biological competition.

Although it has been argued that competition from seeded domestic species is more critical than from resident indigenous species because the former tend to dominate the early postlogging or postburn community, it should be realized that native vegetation can negatively influence tree seedling survival and growth in the absence of seeding. For example, Horton (1950) noted that the presence of naturally-occurring annual grasses and forbs reduced the survival of Coulter pine in southern California, particularly during the first year after planting. Most of the pine losses occurred in the dry late summer and fall, suggesting that competition for water between pine and herbs was the causative factor. Additional indirect evidence of this was given by the fact that survival of pine was greater in plots where the herbs had been clipped to reduce transpiration losses (Horton 1950). Similarly, survival of ponderosa and Jeffrey pine planting stock was best on soils free of native vegetation, with differences in survival apparently associated primarily with differences in soil moisture supply (Roy 1953).

Thus, it still remains to be demonstrated that the competition from introduced species is more severe than that imposed by native vegetation over the long-term. Furthermore, the negative impact of competition from introduced plants must be assessed relative to the benefits derived from seeding, such as the production of forage and erosion control.

3.2.1.2 Options for Reducing Competition

Considerable effort has been expended on reducing grass competition through chemical and mechanical means. Preest (1977) reported that the ephemeral rise in available soil moisture resulting from weed control not only caused immediately increased Douglas-fir growth in Oregon, but also had highly significant positive effects on tree growth for several subsequent years. Gordon (1962) used 2,4-D and dalapon to kill broadleaved plants and graminoids, respectively, and found that ponderosa and Jeffrey pine grew faster when perennial bunchgrasses were destroyed than when bunchgrass plus broadleaved shrubs or broadleaved plants alone were eliminated.

Survival of ponderosa pine planted in orchardgrass, timothy, hard fescue and pinegrass was increased considerably by spraying atrazine or dalapon before planting in trials by Stewart and Beebe (1974) in central Washington. However, mechanical removal of the vegetation (scalping) was found to be less effective (Stewart and Beebe 1974). Dalapon is known to be injurious to Douglas-fir and grand fir when used alone for weed control, but was used safely and beneficially when combined with atrazine and 2,4-D (Newton annd Overton 1973). Atrazine has been applied successfully on its own to establish ponderosa and Jeffrey pine transplants in perennial grass stands (Crouch 1979, Eckert 1979).

Blackmore and Corns (1979) found excellent initial control of perennial herbaceous vegetation, mainly bluejoint, with glyphosphate on lodgepole pine and white spruce plantations in western Alberta. However, within 14 months after spraying the treatment was reduced in effectiveness by 25-50% (Blackmore and Corns 1979).

These studies have clearly demonstrated that chemical control of herbs and shrubs benefits conifer growth. Nevertheless, such methods of decreasing competition should not be used in integrated resource management where the production of forage as well as trees is regarded as a legitimate and desirable use of the forestland base.

Although it must be acknowledged that competition certainly exists between herbaceous and young woody plants, specific grass species may differ in their respective effects on tree establishment. For example, Larson and Schubert (1969) grew ponderosa pine seedlings in competition with two native caespitose grasses in both laboratory and field trials in Arizona. They demonstrated that roots of Arizona fescue initiated growth several weeks earlier than either mountain muhly or pine roots. Predictably, fescue proved to be a much stronger competitor than muhly (Larson and Schubert 1969).

In experiments carried out on burned forestland in California, ponderosa pine was planted with eight species of domestic grass, all sown individually on separate field plots (Baron 1962). When planted simultaneously with these eight grasses, pine was not seriously affected by big bluegrass, pubescent wheatgrass, redtop and hard fescue, but was hindered by tall oatgrass, perennial rye, timothy and orchardgrass. Unfortunately, selective grazing by cattle, particularly on bluegrass and wheatgrass, produced confounding effects and likely influenced the results of this study.

Gjertson (1949) warned that caution should be exercised when seeding sod-forming grasses on reforested sites. However, he added that a survey of 52 seeded areas in ponderosa pine forests of Washington and Oregon failed to show any harmful effects from rhizomatous grasses on pine regeneration. Interestingly, Clark and McLean (1975) found better growth of lodgepole pine seedlings in competition with native rhizomatous pinegrass than with cultivated non-rhizomatous orchardgrass under controlled growthroom conditions.

The studies summarized above suggest that the selection of less competitive grasses may minimize harmful interactions with tree seedlings. However, the data were limited in geographical scope, habitat types and species tested. Further, confounding effects in some experiments precluded the statement of definite conclusions.

It has also been hypothesized that inimical competition from grasses may be reduced by planting improved nursery stock. For example, in the Prince George Forest Region of British Columbia, it was demonstrated in field trials by the B.C. Ministry of Forests Research Branch that large experimental 1 + 0 spruce plug stock, produced in a temperature and light controlled environment, grew faster and to a greater size than smaller 2 + 0 bareroot stock after one growing season (Herring 1981). Although future growth performance was speculative, Herring (1981) conjectured that the large initial size and superior growth characteristics of the experimental plug stock would be advantageous in situations where brush competition might hinder tree regeneration. Related studies are being continued by the Research Branch (Herring 1981).

Similarly, Beveridge and Klomp (1973) found that large, high quality radiata pine seedlings tolerated grass competition better than smaller stock on a site cleared of indigenous forest in New Zealand. Carmean (1971) noted good survival of large red pine seedlings during the first growing season after planting in Minnesota, but poor survival and growth in the second growing season. He suggested that the planting of sturdy, well-balanced stock should be accompanied by control of competing vegetation.

Proper timing of planting may also decrease detrimental grass-tree interaction. If tree seedlings are planted concurrent with or prior to grass seeding, survival and growth are generally satisfactory. For instance, Baron (1962) found that ponderosa pine established successfully on a burned area when planted or direct-seeded simultaneously with grass the first year after the burn. New pine plantings in the second and third years were progressively poorer. When measured six months following planting, mortality averaged 32% for trees planted the same year as grass seeding, 60% for trees planted one year after seeding, and 87% for trees planted two years after seeding (Baron 1962). Clark and McLean (1978) recommended that grass should not be sown more than one year prior to restocking clearcuts by artificial reforestation methods and, since most grass stands increase in density during the first three years after seeding, lighter seeding rates should be used to reduce early competition with tree seedlings. However, lighter seeding rates may diminish the chance of successful grass establishment and produce less forage for range livestock.

Fertilizer applications may or may not assist in the establishment of tree seedlings when grown in competition with grasses. Duffy (1974) noted that when weeping lovegrass was planted and fertilized to protect a site in Mississippi from erosion, associated loblolly pine seedlings were overwhelmed. However, when most of the fertilizer was delayed until later in the growing season the pines could apparently become well established before the grass began its rapid growth in response to the second fertilization (Duffy 1974).

Production of grass was also found to be stimulated by fertilizers on a radiata pine plantation in Australia, with accompanying negative effects on tree seedling growth (Squire 1977). Similarly, Crouch and Radwan (1981) found that N and P applications to increase height growth of young Douglas-fir in Washington and Oregon plantations did not affect the trees sufficiently to be of any practical importance, but adjacent grass stands flourished and almost obscured shorter trees.

White (1977) observed that five years after fertilizing a newly-planted slash pine plantation in northern Florida, total production of live understory and total grasses were not affected, but species composition shifted from dominance of undesirable pineland three-awn on unfertilized plots to a preponderance of palatable bluestem species in fertilized areas. No results were reported for tree response to the fertilizer treatment.

The general observation from these studies has been that grasses tend to respond more to nutrient additions than do associated trees. Further, it has been pointed out that the amount of nitrogen applied may be of critical importance to tree health and survival. For example, Winston (1974) indicated that urea fertilizer increased mortality of jack pine seedlings in direct relation to the rate of nitrogen application.

3.2.1.3 Silvicultural Benefits from Competition

In some circumstances grass competition may prevent the over-stocking of natural lodgepole pine regeneration (Evanko 1953b; McClure 1958; Denham 1959). Schimke et al. (1970) demonstrated that the competition afforded by perennial grasses reduced both the size and number of trees and brush seedlings, thus effectively maintaining a forest fuel-break in central California. However, Rindt (1965) argued that manipulation of grass density was difficult to use to good advantage for silvicultural purposes. He claimed that it was limited to special sites and to infrequent years when all of the essential conditions for establishment of overdense pine stands coincided. According to Rindt (1965) these conditions entailed the simultaneous occurrence of a heavy seed crop, favourable soil moisture and the absence of native competitors.

In the Nelson Forest Region, Utzig et al. (1938) described a specialized grass mix comprised of redtop, creeping red fescue, Kentucky bluegrass and smooth brome specifically designed to compete with and naturally space regenerating lodgepole pine seedlings to acceptable re-stocking levels. However, it was not indicated whether the efficacy of this mix had been tested experimentally.

In experimental seedings on lodgepole pine burns in eastern Oregon, Pickford and Jackman (1944) showed that heavy stands of seeded grass decreased the number of pines establishing on these sites (Table 20). They pointed out that quick-starting species, such as timothy, slender wheatgrass, meadow fescue and tall oatgrass, were the chief agents in controlling tree seedling density (Pickford and Jackman 1944). It should be noted that the intensity of the burns also played a significant role in the survival and growth of trees, as well as of herbage, in these experiments (Table 20).

TABLE 20. Effect of seeding forage plants on the establishment of lodgepole pine on burns in eastern Oregon (Pickford and Jackman 1944)

Seeded Grass Species	Elevation (m)	Burn Intensity	Herbage Biomass (kg/ha)	Herbage Density ('000/ha)	Pine Density (#/ha)
Crested wheatgrass, Kentucky bluegrass, Timothy	1,700	Moderate	1,095	1,625	0
Slender wheatgrass, Mountain brome, Orchardgrass	1,700	Moderate	699	2,890	430
Meadow fescue, Chewing's fescue, Highland bentgrass	2,000	Heavy	82	No data	430
Slender wheatgrass, Crested wheatgrass, Smooth brome, Alta fescue	2,000	Heavy	212	No data	324
Unseeded	2,000	Light	96	No data	6,904
Unseeded	1,700	Moderate	41	No data	6,024
Unseeded	2,000	Heavy	95	No data	358

The effects of this biological interaction may be non-selective from a silviculturist's point of view, but ecologically it has been suggested that those pines which survive competition may represent the "fittest" or best-adapted members of the tree population (B.M. Wikeem, pers. com.)[5]. However, the feasibility of using grass competition as a "silvicultural tool" for thinning tree regeneration to specified stocking densities has yet to be demonstrated.

3.2.1.4 Allelopathic Interactions

Tree/grass interactions may include the phenomenon of allelopathic interference as well as competition for available water or nutrients. Such interference occurs when a plant produces chemical substances which inhibit the germination, growth or development of adjacent plants of the same or different species (Whittaker and Feeny 1971).

Allelopathy is believed to be important in the survival and growth of trees in both plantations and natural stands. Fisher (1980) stated that an awareness of this phenomenon, and its potential effects on regeneration and site productivity, was essential to the practice of intensive silviculture.

In laboratory experiments, Rietveld (1975) found that a growth-inhibiting substance was produced in live foliage, and to a lesser extent in dead residues, of Arizona fescue and mountain muhly which was capable of substantially reducing total germination as well as retarding germination rate and initial radicle development of ponderosa pine. Similar results were reported by Jameson (1968). In laboratory trials, he found that extracts of Arizona fescue foliage were more detrimental to growth and development of ponderosa pine than bottlebrush squirreltail or blue grama (Jameson 1968). In eastern North America a number of old-field herbs, particularly goldenrod, have been shown to exhibit allelopathic effects on jack pine (Brown 1967), black cherry (Horsley 1977) and sugar maple (Fisher et al. 1978).

The reciprocal relationship can also occur; trees may influence understory vegetation through chemical means. For example, Jameson (1966) provided evidence suggesting that pinyon/juniper litter may release a substance which reduces growth of blue grama grass. McConnell and Smith (1971) reported that ponderosa pine needle litter had a significant effect on initial survival of fescue seedlings. They proposed that thick accumulations of needle litter and its by-products may exert a strong selective pressure on the eventual composition and cover of understory vegetation. However, no direct proof of allelochemical activity was presented.

3.2.2 Interspecific and Temporal Dynamics of Seeded Forages

The fate of individual species in a forage mix and their respective contributions to total cover or biomass over time has not received much attention in the literature. No published studies were found which investigated temporal trends in species abundance and distribution within seeded stands in British Columbia. Outside the province, post-seeding evaluation of the stand success has often been limited to one or two years of visual assessment. Rarely have systematic sampling programs been implemented to monitor the synecology of introduced grasses and legumes on logged and/or burned sites.

3.2.2.1 General Trends

Based on general observations, McClure (1958) stated that grass seedings on burned-over forestland in the Pacific Northwest usually required one year for establishment, produced heavily during the following two growing seasons, then declined in production 30-40% and remained relatively stable at this new level for several years. In contrast, many studies have shown that recovery of native herbs and shrubs is often quite slow following severe disturbance (Section 3.2.3). For example, Helvey and Fowler (1979) found that average plant cover on a mixed coniferous forest clearcut in northeast Oregon was 56% on a seeded portion, with introduced grasses comprising 46% of the cover, but only 20% on an unseeded portion two years after logging and seeding.

The initial dominance of introduced species in seeded stands is probably due primarily to the wide dissemination and abundance of domestic seed compared to viable indigenous seed. However, work by Smoliak and Johnston (1968) on southern Alberta prairie rangeland with several cultivated and native grasses revealed that the introduced species were generally superior to the native plants in percentage germination and speed of germination. In addition, domestic grasses germinated, emerged and grew more readily at lower root-zone temperatures, suggesting that early establishment and successful juvenile growth of cultivated species may give them a competitive advantage over indigenous graminoids during the early stages of succession. Cultivated species in this experiment included smooth brome, crested wheatgrass, orchardgrass, Russian wildrye, pubescent wheatgrass and creeping red fescue. The native grasses were blue grama, needle and thread, junegrass, rough fescue, little bluestem and Parry's oatgrass (Smoliak and Johnston 1968).

---

[5] Manager, Range Research, B.C.M.O.F.

These results may not apply to native species characteristic of forest range. For example, McLean (1967b) tested the germination requirements of 25 shrubs and herbs commonly found in forests within the IDF zone of British Columbia. In laboratory trials it was found that 17 species germinated at low temperatures after prolonged stratification. McLean (1976b) suggested that these species could presumably overwinter under snowcover and germinate shortly after snowmelt, enabling them to become established before tame grasses seeded in the spring. However, emergence and rate of growth following germination were not investigated in this study; nor were comparative analyses made with cultivated species.

Although introduced grasses initially dominate the post-harvest plant community, they are eventually replaced by native vegetation. This was clearly demonstrated in a longterm study by Lyon (1976) on the Sleeping Child burn in western Montana. A mix comprised of orchardgrass, hard fescue, timothy, smooth brome, cereal ryegrass and white clover was aerially seeded at a rate of 16 kg/ha the year after the burn. Vegetal cover and frequency of occurrence data were collected from 12 systematically located transects; annually for the first 6 years after seeding and biennially for the remaining 6 years of study.

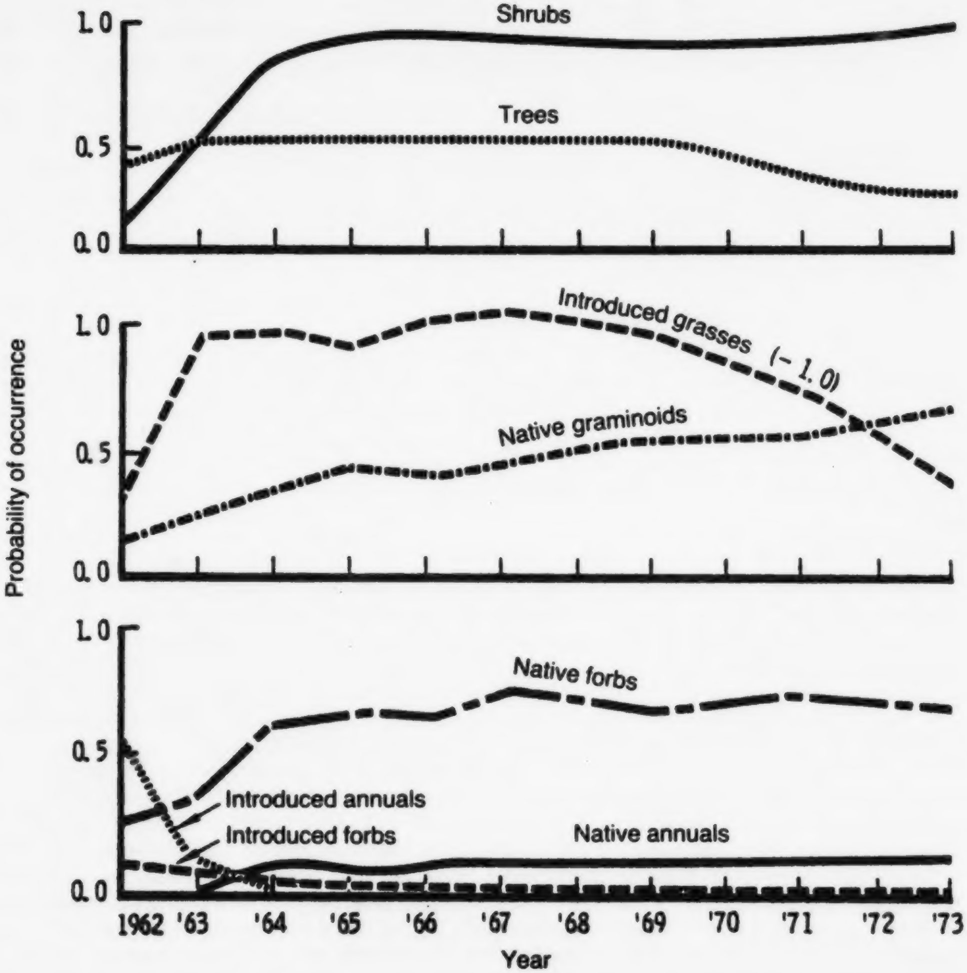

FIGURE 3. Probabilities of occurrence in sample plots for eight plant groups on the Sleeping Child burn, Montana, 1962 to 1973 (Lyon 1976).

During the first growing season 66% of all cover on the lodgepole pine burn was provided by *introduced* plants, but by the *12th season seeded* species only accounted for 17% of the total vascular plant cover. Figure 3 depicts the average combined frequency of occurrence for 8 major plant groups on 11 transects, expressed as the probability of finding a representative of the group in a random sample plot. These frequency of occurrence data indicate that all plant groups had stabilized by the fourth post-fire growing season and only the "native graminoids" category continued to rise after that time. While native graminoids increased steadily over the duration of the study, seeded grasses began to decline in frequency after 1967.

Biological competition is probably the most important ecological factor responsible for decreasing yields of domestic species as succession advances. Lyon (1976) postulated that the grasses and legumes introduced to the Sleeping Child burn were apparently unable to compete with native herbs and shrubs during the dry western Montana summers. However, these forages were also subject to selective grazing by cattle.

The influence of root competition between trees and herbs may be of significance long before overstory effects become evident. For example, Basile and Jensen (1971) found that native herbage yields had started to decline after 10 years on lodgepole pine clearcuts in Montana although tree canopy cover averaged only 7%. They suggested that by 10 years of age the roots of tree seedlings had grown sufficiently to gain a competitive advantage over herbaceous plants for available soil moisture. However, no experimental evidence supporting this was given.

The highest productivity and rate of development of introduced grasses and legumes logically occurs on sites with the most favourable edaphic properties for plant establishment and growth. For instance, Anderson and Brooks (1975) seeded big bluegrass, crested wheatgrass and hard fescue on a dry Pine/Sedge site; hard fescue, intermediate wheatgrass and timothy on a mesic Pine/Mixed Fir site; and intermediate wheatgrass, timothy and orchardgrass on a wet Mixed Fir site within a burned forest in Oregon. Changes in percent ground cover were measured over the succeeding four years.

It was found that the rate and degree of development was least in the relatively xeric Pine/Sedge habitat and greatest in the moister Mixed Fir habitat, even though the species sown on each site were adapted to the local soil moisture conditions. Percent ground cover of introduced grasses peaked in the third year following seeding at the two drier locations, and after only two years on the wet Mixed Fir site.

Similarly, Orr (1970) detected differences in plant cover development on sites with contrasting soil textures. Timothy, smooth brome, Kentucky bluegrass and yellow sweetclover were sown on coarse-textured and fine-textured soil types on a ponderosa burn in the Black Hills of South Dakota (Orr 1970). Sparse and dense ground cover were sampled separately on each of the two sites over a four-year period.

It was found that ground cover developed more rapidly and to a higher initial density on the coarse-textured soil at the City Creek site than on the finer-textured, limestone-derived soil of the Pine Crest site (Figure 4). Plots with dense ground cover generally had the highest percentages of seeded plants.

A steady increase in percent cover of seeded grasses was noted during the first three years after seeding on both sites, followed by a decline in the fourth year at City Creek and a stabilizing trend at Pine Crest. The drop in vegetal cover at City Creek suggested that maximum production of live vegetation on the coarse soil occurred early. Despite the slower plant development at Pine Crest, Orr (1970) speculated that the fine-textured soil had the higher production potential of the two sites.

The study of trends in the abundance and distribution of cultivated plants sown on disturbed forestland is complicated because the seeded forage plants interact not only with each other, climate, soils, topography and native vegetation, but also with wildlife, livestock and invertebrate consumers. The complexity of these ecological interrelationships appears overwhelming. However, given a specific mix of adapted domestic plants, a specific habitat with characteristic native flora, and specific management objectives, the identification of predictable trends in species abundance should be possible.

For example, Krueger et al. (1980) investigated the effects of different combinations of grazing and seeding treatments on plant succession in a northeast Oregon clearcut. The clearcut was divided into three 2 ha pastures. The upper slope of each pasture was in the Douglas-fir/ninebark habitat type (*sensu* Daubenmire 1952; Daubenmire and Daubenmire 1968), and the lower slope was in the grand fir/pachistima type.

Five 0.2 ha plots in each pasture were sown to domestic grasses and the remaining five plots were left unseeded as controls. The plots were aligned so that the upper half of each plot lay in the Douglas-fir/ninebark habitat type and the lower half in the grand fir/pachistima type. In plots designated for seeding, the lower half was sown to a mixture of orchardgrass, timothy, smooth brome and white clover. The upper half was further divided into two equal subplots, one sown to blue wildrye and the other to mountain brome. Grazing treatments were: cattle only, big game only, and cattle with big game.

Analysis of plant species frequency data revealed that each treatment or combination of treatments led to the development of a different plant community over the 14 year study period. Krueger et al. (1980) concluded that, to a certain degree, plant succession could be managed to produce a predetermined plant community.

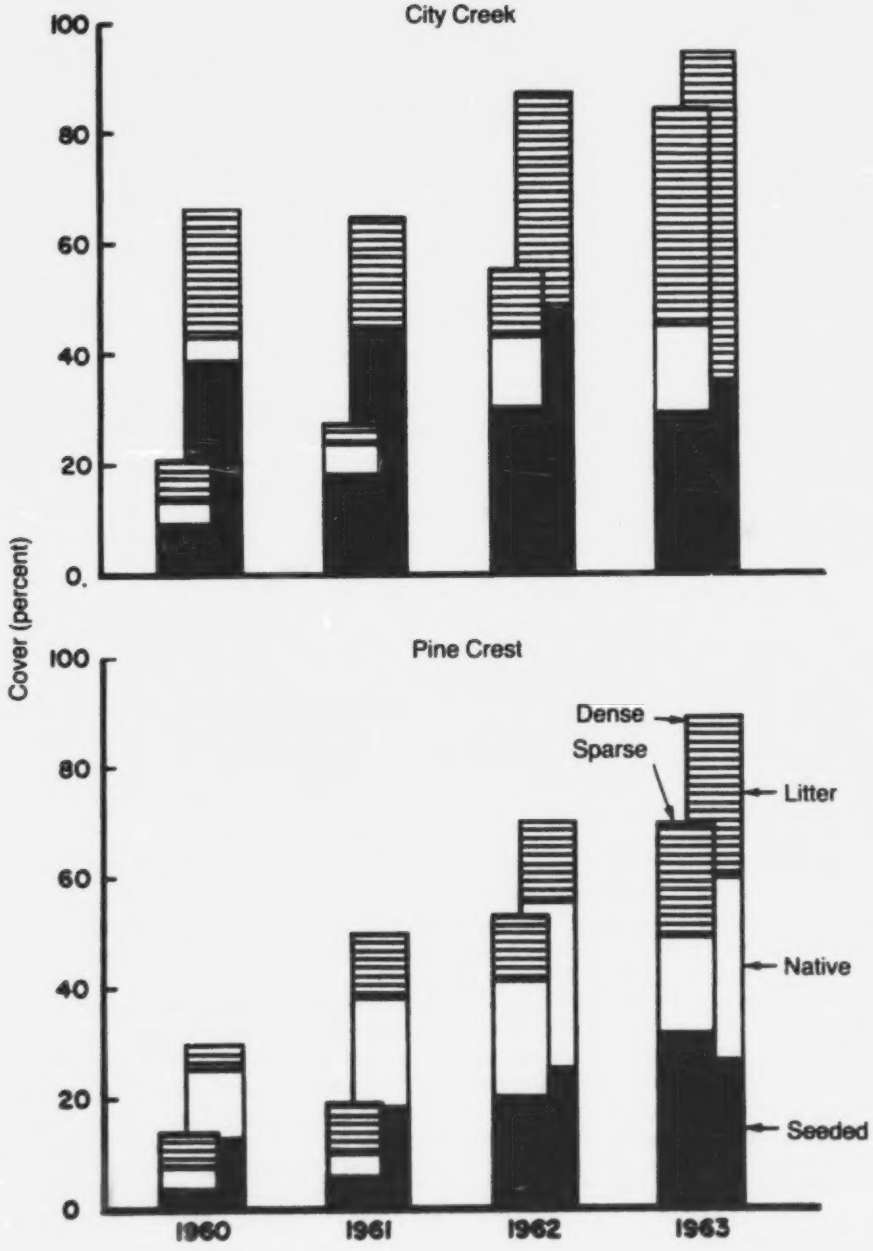

FIGURE 4. Live vegetation (native and seeded) and litter-density trends at two sites on a forest burn in the Black Hills, South Dakota. Each bar represents the yearly average of four plots (Orr 1970).

3.2.2.2 Species Population Trends

A plant species population is shaped by the physiology, morphology, longevity, reproductive capacity and competitive ability of the species in relation to the physical surroundings and associated members of the biological community. These factors determine the survival or mortality of individual plants within a species, which, in turn, determines the population density and distribution of the species within a plant community.

Plants co-existing in natural communities are believed to have evolved different niches, resulting in a certain degree of resource partitioning among species. The introduction of new species disrupts the dynamic equilibrium of a natural plant community and creates instability. Readjustments in species composition and abundance, and consequently in patterns of resource use, occur as the plant populations of individual species influence or react to other constituents of the plant community.

Domestic forage grasses and legumes seeded on disturbed forestland are not integral components of the native vegetation. Thus, the persistence of introduced species populations depends on an ability to successfully propagate themselves by reseeding or vegetative reproduction as native plants recolonize the post-harvest site. This, in turn, depends on the faculty of the domestic forages to resist physiological stresses associated with competition or grazing.

No studies in British Columbia have documented temporal trends in abundance and distribution of seeded forage species. Outside of the province, several published papers have provided some information on this subject. However, no research was found which analyzed the competitive interactions of seeded species, either within the forage mix or with native plants, on disturbed forest range.

More than 40 grasses and legumes are sown or recommended for sowing on clearcuts, landings, logging roads and burns throughout the Pacific Northwest (Tables 11 and 13). Unfortunately, data on long-term changes in plant cover are available for only a few species. These include timothy, orchardgrass, smooth brome, crested wheatgrass, sweetclover and white clover.

Timothy has been found to establish readily on burned mixed coniferous forestland in northern Idaho (Christ 1934) and Oregon (Anderson and Brooks 1975), ponderosa pine forests in South Dakota (Orr 1970) and Oregon (Wilson 1949), and lodgepole pine forests in Montana (Lyon 1976). Christ (1934) pointed out from observational evidence that while timothy was eventually crowded out by other species, it often maintained high production for a period of 20 years or more in seeded stands in Idaho. Lyon (1976) noted that timothy produced cover on the Sleeping Child burn in western Montana in the 2–3% range for the first 5 years after seeding, then gradually declined to less than 1% over the next 7 years.

Orchardgrass has been found to establish and grow well in moist habitats. Anderson and Brooks (1975) seeded orchardgrass along with timothy and intermediate wheatgrass on a wet Mixed Fir site in Oregon, and observed that two years after seeding this species accounted for 61% of the total perennial grass cover. On a lodgepole pine burn in western Montana, orchardgrass increased from 1% cover the first growing season after seeding to 8.9% by the tenth season. However, two dry years in a row reduced orchardgrass cover to less than 2% in the 12th year (Lyon 1976).

Christ (1934) reported that where smooth bromegrass was used in reseeding experiments on burned-over mixed coniferous forest in northern Idaho, the stands obtained have usually been poor. This was also found to be the case by Lyon (1976) on a lodgepole pine burn in Montana where smooth brome contributed 1% cover the second year after seeding and then dropped below that level for the remaining 10 years of the study. In contrast, smooth brome was observed to provide substantial cover two years after seeding on a ponderosa pine burn in Oregon, and continued to be a prominent member of the community for the next seven years despite heavy grazing by sheep (Wilson 1949).

It has been reported that crested wheatgrass is well adapted to arid environments, but usually is not readily established when broadcast seeded (Christ 1934). However, Anderson and Brooks (1975) obtained good stands of aerially seeded crested wheatgrass on dry Pine/Sedge sites in a burned mixed coniferous forest in Oregon. Within four years after seeding, this species had begun to spread from the Pine/Sedge habitat to an adjacent, unseeded area (Anderson and Brooks 1975). Crested wheatgrass was also observed to establish well initially on a ponderosa pine burn in Oregon (Wilson 1949), but nine years after seeding the best stands were found only on shallow, rocky soils.

Legumes have generally not persisted very long in seeded stands. Wilson (1949) noted that alfalfa, hairy vetch and sweetclover established poorly on burned ponderosa pine forest in Oregon, and had virtually disappeared nine years after sowing (Table 21). Similarly, Anderson and Brooks (1975) found that white Dutch clover, lana vetch and rose clover did not establish well on burned mixed coniferous forestland in Oregon, and declined dramatically after the first year. Orr (1970) reported that hairy vetch failed to establish on a ponderosa pine burn in South Dakota, while yellow sweetclover almost completely disappeared after the third growing season. On a lodgepole pine burn in western Montana, Lyon (1976) observed that white clover was eliminated from the seeded stand within four years.

TABLE 21. Trends in seeded species on burned ponderosa pine forestland in Oregon based on field inspections (Wilson 1949)

Species	1940	1941	1948
Alfalfa	6*	9	sparse
Bluegrass, bulbous	11	5	sparse
Brome, mountain	10	4	sparse
smooth	4	2	2
Oatgrass, tall	1	1	1
Orchardgrass	5	7	**
Rye, perennial	2	10	**
Sweetclover	8	8	absent
Timothy	7	6	**
Vetch, hairy	9	11	absent
Wheatgrass, crested	3	3	sparse

* Numbers refer to order of species predominating in seeded area.
** Not discussed.

Data on short-term trends were available for a few other species. For example, in a burned mixed coniferous forest in Oregon, big bluegrass cover rose from 14% in the first year to 22% in the third year after seeding on a dry Pine/Sedge habitat type (Anderson and Brooks 1975). However, cover declined to 14% in the fourth year. In the same study, ground cover of intermediate wheatgrass was found to peak at 38% and 20%, respectively, on Pine/Mixed Fir and Mixed Fir sites three years after seeding. Percent cover dropped on both sites for this species in the fourth year.

Kentucky bluegrass cover was very low on a coarse-textured soil (City Creek site) two years after seeding on a ponderosa pine burn in South Dakota (Orr 1970). However, bluegrass cover increased sharply during the third year in apparent response to above-average precipitation (Figure 5). Interestingly, Kentucky bluegrass failed to become an important cover component on the fine-textured Pine Crest site (Orr 1970).

On a ponderosa pine burn in Oregon, Wilson (1949) found that perennial ryegrass drastically declined in importance by the second year after seeding (Table 21). This result was in accord with observations noted by Christ (1934) and Carr (1980) concerning the biology of this species. Similarly, cereal rye seeded on a lodgepole pine burn in Montana provided only slight cover and had essentially disappeared by the fourth growing season (Lyon 1976).

It is interesting to note that tall oatgrass remained a dominant species nine years after sowing in Wilson's (1949) study. Carr (1980) reported that this species generally reached full production in two or three seasons, and further longevity depended upon natural reseeding. He considered perennial ryegrass and tall oatgrass to share similar growth characteristics, and classified them together as "rapid-developing, short-lived grasses".

3.2.3 Successional Development of Native Vegetation

Recolonization of disturbed forest sites by native species has a significant impact on the growth and development of introduced forage plants and seeded or planted conifers. The rate and pattern of secondary plant succession on clearcut blocks or forest burns depends on the degree of site disturbance and compaction, kind and amount of residual vegetation, ingress of wind-dispersed weeds, introduction of forage grasses and legumes, influence of variable climatic factors and the silvicultural activities of forest managers.

In interior British Columbia, researchers have made some attempt to document the re-establishment of native plants on logged sites in specific biogeoclimatic zones. In the SBS zone north of Prince George, Eis (1981) recorded the rate of invasion and height growth of native herbs and shrubs on clearcuts planted to white spruce. Four forest-site types, described in detail by Illingworth and Arlidge (1960), were examined: Cornus/Moss, Devil's Club, Aralia/Dryopteris and Alluvium. The latter two are considered to have high potential for native range or tame pasture in the SBS (Pojar et al. 1982).

In general, Eis (1981) found the rate of invasion to be relatively slow with the exception of the moist, fertile Alluvium site. On this forest-site type re-establishment of shrubs and grasses on clearcuts was so immediate and rapid that colonization of pioneer annual herbs was usually prevented. While the height of most shrub species, including twinberry, mountain alder and thimbleberry, was almost mature by the end of the first growing season, their density continued to rise for several more years. Three years after logging the whole area was overgrown by shrubs except for roads and landings where reedgrass and wood-reed formed thick, deep mats. However, as the shrub canopy closed, the proportion of grasses decreased.

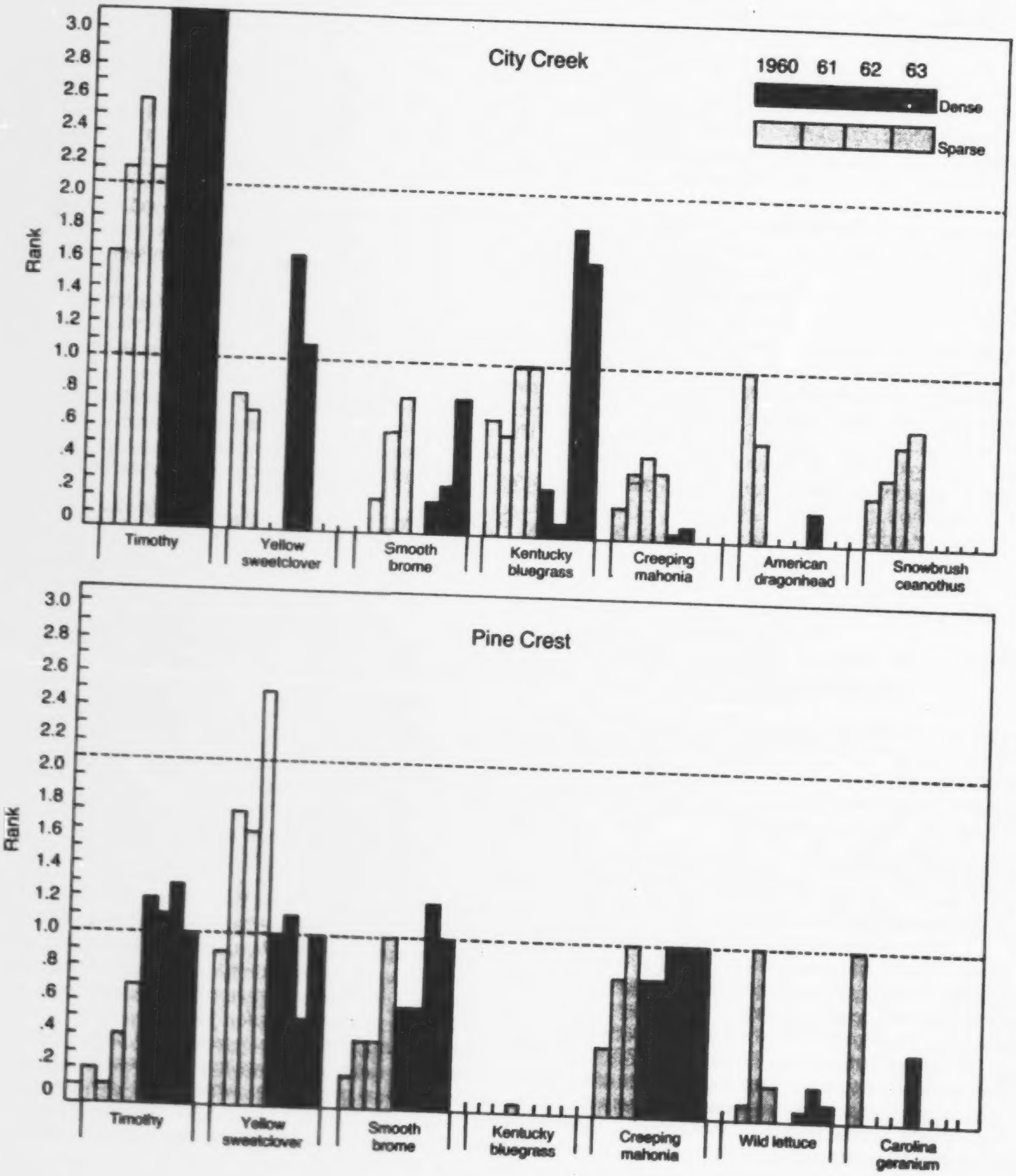

FIGURE 5. Dominant ground cover composition trends in terms of cover rank at two sites on a forest burn in the Black Hills, South Dakota. The three dominant species were ranked 3, 2, or 1 in descending order of abundance and proportion of ground cover to define general ground cover density and composition trends (Orr 1970).

On the other three site types, Eis (1981) noted an increase in the rate of recolonization associated with an increasing moisture gradient from the dry Cornus/Moss type to the progressively moister Aralia and Devil's Club types. Migrant annuals such as fireweed were the first and most aggressive colonizers. Biennials and perennials did not appear in great numbers until the fifth year following logging, although perennial grasses were found to form dense, continuous mats as early as the third or fourth years on the Devil's Club site type (Eis 1981). The shrubs, mainly trembling aspen, mountain and Sitka alders, red raspberry, thimbleberry and black twinberry, were the slowest to recolonize clearcuts on these three site types.

Eis (1981) pointed out that since the annuals started from seed every year and the mature plants died every fall, these species rarely constituted a serious obstacle to spruce regeneration. Native perennials were observed to compete more vigorously than annuals with young spruce seedlings because their growth from overwintering rootstocks was very rapid in the spring and gave them a competitive advantage. The shrubs were also found to reduce conifer growth, particularly after the sixth or seventh year. As their height and density increased, the resulting shade became progressively more detrimental to regeneration of white spruce (Eis 1981).

In the Nelson Forest Region of southeastern British Columbia, Smith and Wass (1976) measured percent ground cover of recolonizing native vegetation on clearcuts ranging from 1 to 23 years of age in the ESSF, ICH and IDF biogeoclimatic zones. Postlogging treatments were burned versus non-burned. Data were collected separately for logging roads and areas between roads.

The results revealed that vegetative cover 10 years after clearcut logging in this region averaged approximately 35% on heavily compacted main roads, 55% on skidtrails, 65% on burned areas between roads and 72% on unburned areas between roads (Smith and Wass 1976). Burned clearcuts had a residual botanical cover of less than 5% immediately after treatment, but this cover increased at a faster rate than the increase in cover on unburned cutblocks. However, the burned clearcuts never did attain as dense a cover as the unburned sites during the period encompassed by the investigation. This was mainly because the interval between logging and slashburning created a considerable time lag in plant recovery. Vegetative cover on unburned surfaces between roads was initially greater than cover on the roads, but within six years the rate of increase in cover on the latter exceeded the former (Smith and Wass 1976).

Highest postlogging vegetative cover occurred in the IDF zone; this zone was also the least affected by burning (Table 22). Slowest plant recovery after burning occurred in the ESSF. Unfortunately, Smith and Wass (1976) did not examine the response of individual species populations to the modified environmental conditions induced by logging and burning.

TABLE 22. Average vegetative cover (%) between roads in clearcuts logged 3, 4 and 5 years prior to sampling in three biogeoclimatic zones in the Nelson Forest Region, B.C. (Smith and Wass 1976)

Biogeoclimatic Zone	Unburned	Burned
Interior Douglas-fir	71.6	72.4
Interior Cedar/Hemlock	59.6	38.9
Engelmann Spruce/Subalpine Fir	65.5	28.4
Combined Averages	**65.6**	**46.6**

Research outside of British Columbia tends to support the findings of Eis (1981) and Smith and Wass (1976). Rummell and Holscher (1955) reported that on eastern Oregon and Washington ponderosa pine and mixed fir forest ranges more than 30% of the original understory vegetation may be destroyed by logging. They added that although indigenous plants usually recolonized the denuded ground within four years, this vegetation consisted mainly of undesirable weedy species. Compacted landings and skidtrails often required more than four years to re-establish a vegetative cover (Rummell and Holscher 1955; Garrison 1960).

Similarly, Strickler and Edgerton (1976) indicated that native herbs and shrubs recovered on disturbed forest soils within one to three growing seasons after timber harvest in mixed coniferous forests of eastern Oregon. They noted that annuals and biennials generally dominated the initial plant cover, while perennials developed more slowly. Similar trends in plant establishment following forest disturbance in Oregon, Washington and British Columbia have been discussed by Garrison and Rummell (1951), McClure (1958), Denham (1959), Hedrick et al. (1968), Eddleman and McLean (1969) and Eis (1981).

Recovery of native plant species was monitored on logged ponderosa pine range in northeastern California (Hormay 1940) and in both eastern Oregon and eastern Washington (Garrison 1960). A significant finding in both studies was that grasses underwent the greatest reduction in cover and were slower to recuperate than forbs and shrubs. Grass species included Idaho fescue, western needlegrass and Sandberg's bluegrass in California, pinegrass in Oregon, and fescue and wheatgrass species in Washington (Hormay 1940; Garrison 1960).

Garrison (1960) reported that seven years after disturbance on the Oregon site, total understory cover was 11% greater than before logging. However, forbs such as yarrow, lupine, strawberry, gland cinquefoil, stonecrop and woollyweed were overabundant and disproportionately represented in comparison with their initial status. These species were all considered to be poor cattle forage (Garrison 1960). Grasses and shrubs had merely regained their prelogging densities after seven years. Furthermore, vegetative recovery on heavily compacted skidtrails was severely retarded, with development arrested at a stage equivalent to that existing two years after logging.

On the Washington site, Garrison (1960) noted that slash burning on some of the sample plots had resulted in further reductions in herb and shrub cover beyond that experienced from tree falling and skidding. By the end of the seventh growing season, recovery of the Washington study area was much further behind those areas examined in Oregon because of the aggressive invasion of cheatgrass, prolific spread of snowberry and failure of some perennial grasses such as Idaho fescue to re-establish on the site.

The amount of soil disturbance affects the rate and degree of vegetative development. For example, Hedrick et al. (1968) presented data illustrating native herbage response to soil disturbance three years after sanitation logging in a mixed coniferous forest in northeastern Oregon (Table 23). Herbage production per unit area was greater where the surface soil was slightly disturbed than on undisturbed forest soil. This difference was attributed to: (1) the removal or thinning of the overstory by logging which created beneficial light conditions on disturbed soil for enhanced understory productivity, and (2) the fact that the growth of pinegrass, the most abundant and prolific herb on the site, was apparently stimulated by moderate amounts of soil disturbance.

In contrast, areas with subsoil disturbance were quite unproductive and slow to recover (Table 23). On such heavily damaged sites in Oregon, undesirable weedy species such as bull thistle frequently dominated the developing plant community for several years (Hedrick et al. 1968; Edgerton 1971; Hedrick 1975; Miller and Krueger 1976; Krueger 1983).

TABLE 23. Native herbage yield after 3 growing seasons in relation to the extent of soil disturbance caused by logging in mixed coniferous forest of northeastern Oregon (Hedrick et al. 1968)

Soil Disturbance Class	Percent of Area	Herb Yield (kg/ha)
No disturbance	61	245–305
Surface disturbance	24	325–405
Subsoil disturbance	15	75–115

Hedrick et al. (1968) also noticed that shrubs native to the mixed coniferous forest, especially ninebark and oceanspray, were released by sanitation cutting. Both cover and current annual growth measurements were higher in logged stands as opposed to unlogged (Hedrick et al. 1968). These results are comparable to those of Eis (1981) in northcentral British Columbia in which black twinberry, mountain alder and thimbleberry were found to re-establish and develop rapidly on a clearcut logged Alluvium forest-site type.

The native species recolonizing harvested cutblocks may originate not only from surviving residual vegetation, but from immigrant or buried seed. Strickler and Edgerton (1976) conducted a series of greenhouse trials over a one-year period to study seedling emergence in samples of forest litter and surface soil from a grand fir/lodgepole pine/Englemann spruce/western larch forest in eastern Oregon. The samples were subjected to four different heat treatments of 28 (control), 60, 80 and 100°C, and three shading treatments of unshaded (control), 80 and 92% shade. These regimes simulated postlogging environments.

By the completion of the study, 38 species had emerged, consisting of 29 forbs, 4 grasses, 1 sedge and 4 shrubs (Strickler and Edgerton 1976). An early flush of seedling emergence occurred in May, mainly from the forest litter samples and primarily composed of species with wind-borne seed such as Watson's willow-weed, common cat-tail, bull thistle and cudweed. Plants whose seeds were not wind-borne, such as gland cinquefoil, lance-leaf figwort, blue elderberry, squaw currant and sticky currant, emerged from soil layers. A second flush of seedling emergence took place in September, with Watson's willow-weed accounting for roughly 80% of these fall germinants.

The 60 and 80°C treatments produced more seedlings than the control, while the fewest seedlings emerged from the 100°C treated samples (Strickler and Edgerton (1976). However, treatment means were not significantly different. The 80 and 92% shade treatments produced fewer seedlings per sample than the unshaded control, but differences were not statistically significant when all species were analyzed together. When analyzed separately, however, the results showed that shade significantly depressed emergence of Watson's willow-weed. Further, there were indications that emergence of other species, such as bladder-fern and mitrewort, was also influenced by shade.

Strickler and Edgerton (1976) found that 66% of all seedlings emerged from the litter. Of these, 83% represented species producing abundant wind-dispersed seed. They concluded that migrant seed appeared to be more important than buried seed in determining composition of the early seral plant community on mixed coniferous forest sites in Oregon.

As pointed out earlier in the discussion of Smith and Wass's (1976) study in southeastern British Columbia, post-logging treatments such as burning affect the development of subsequent vegetative cover. This influence has also been demonstrated by Dyrness (1973) in the western Cascades of Oregon. Plant cover and species composition were compared on logged, old-growth Douglas-fir plots which had been: (1) largely undisturbed; (2) disturbed but unburned; (3) lightly burned and (4) severely burned (Dyrness 1973). After five growing seasons, he found that plots with undisturbed soil conditions had a combined herb, shrub and tree cover value of 108%. Disturbed/unburned plots and lightly burned plots had plant covers of 75 and 78%, respectively. Severely burned plots had an average cover of 62%.

Species diversity was found to be greatest on moderately disturbed or burned soils (Dyrness 1973). Five years after burning, 39 plant species were encountered on undisturbed plots, 56 on disturbed/unburned plots, 48 on lightly burned plots and only 24 species on severely burned plots (Dyrness 1973). He pointed out that plant cover on undisturbed soil tended to be dominated by residual species, while invaders became progressively more important on disturbed and burned soils, respectively. Although Douglas-fir cut-over land in the western Cascades has historically been used for sheep grazing (Ingram 1928; 1931), it is unknown how applicable the results from Dyrness' (1973) study of post-logging vegetation change are to the relatively drier, interior forest ranges.

3.2.4 Summary and Discussion

Following initial establishment of the post-harvest forest community, subsequent successional development alters the population densities and distribution of tree seedlings, introduced grasses and legumes, and native herbs and shrubs. Forest managers seek to maintain desirable tree stocking levels and growth rates by minimizing competition with seeded forages and natural vegetation. On the other hand, range managers wish to sustain forage production and prolong the grazing benefits afforded by introduced species and native plants.

Competition for soil moisture among conifer seedlings, herbs and shrubs is a common occurrence on harvested forest sites throughout the Pacific Northwest. The physiology of perennial grasses is such that they generally withstand drought better than tree seedlings and outcompete them when soils are dry.

Seeded grasses tend to dominate the post-harvest plant community initially, and hence interact more vigorously than recolonizing native species with natural or planted tree regeneration during the early stages of community development. Although chemical treatments are effective means of controlling grass competition, these measures are inappropriate where forage is regarded as a legitimate and useful product of forest ecosystems or where chemicals may have undesirable side effects.

Negative interactions between seeded grasses and trees may be reduced through alternative management options:

(1) Less competitive or "compatible" grass species may be sown on multiple-use forest range. Unfortunately, the existing data on this subject are limited in geographical scope, habitat type and in species tested. Additional research is warranted, particularly regarding the compatibility of commonly-sown domestic grass species with the major conifer species in different biogeoclimatic zones.

(2) Large, high quality tree planting stock may be employed in reforestation efforts on multiple-use forest range. On-going research by the B.C. Ministry of Forests Research Branch is currently pursuing the development of superior planting stock for situations involving both herbaceous and woody competitors. Nevertheless, the economic costs of producing, transporting and planting these seedlings must be balanced against the potential benefits.

(3) The timing of tree planting and forage seeding operations may be synchronized to reduce competition. Studies with ponderosa pine have demonstrated that planting one or two years after grass seeding was less successful than planting and seeding simultaneously. Similar results are expected with conifers such as lodgepole pine, Engelmann and white spruce, subalpine fir and Douglas-fir.

(4) Lower grass seeding rates may reduce early competition with tree seedlings. However, this may also lead to poor grass establishment. As discussed in sections 3.1.2.3.2 and 3.1.3, research is required to determine optimal seeding rates, for seed mixes and for individual forage species, which minimize competition with trees and establish satisfactory grass stands.

(5) The application of fertilizers may assist in tree establishment. However, the available data suggest that grasses respond rapidly and aggressively to the added nutrients, with detrimental impacts on

tree seedling survival and growth. There is evidence which shows that the timing of fertilizer application is important in determining the outcome of this interaction. Thus, further research on this topic is recommended, specifically dealing with rates and timing of fertilization.

Competition may sometimes provide silvicultural benefits in the form of thinning overdense stands of natural tree regeneration. However, the usefulness or efficacy of this interaction for management purposes is questionable. Scientific analysis is necessary to assess the extent, pattern and effectiveness of such "natural thinning" processes in terms of tree spacing and distribution.

Allelopathic inhibition of ponderosa pine germination and radicle development from substances produced by native grasses has been reported in the literature. However, the generality and significance of allelochemical interference in relation to interspecific competition has yet to be determined in successional forest environments. Research should focus on the effect of leachates or residues from living and dead tissues of domestic forages and native vegetation on the germination and juvenile growth of B.C.'s major coniferous species.

Although domestic grasses initially comprise most of the vegetative cover and production in seeded post-harvest forest communities, competition from native plants and the overstory effects due to the developing tree canopy progressively diminish and eventually eliminate the contribution of introduced species to community biomass. The time required to accomplish this varies with tree, herb and shrub species, habitat characteristics, grazing factors (section 3.3.1.3) and management activities. However, as an example, a reduction in seeded plant cover of 50% over a 12 year period on a lodgepole pine burn in Montana has been recorded.

Similarly, trends in individual species populations are determined by the biology of the species within the context of dynamic ecological interrelationships and environmental constraints. Rapid-starting, short-lived species such as perennial ryegrass tend to disappear within a few years after seeding, whereas longer-lived grasses such as orchardgrass may persist for up to a decade or more. Legumes have frequently not established well in broadcast seedings on disturbed forestland in the Pacific Northwest, and often decline drastically within one or two years.

Such generalizations are of only limited value to resource managers who rely on specific data for scientific management of multiple-use forest range. Thus, long-term studies which document changes in seeded species composition and production over time should be initiated in different biogeoclimatic zones,including the BWBS, ESSF, ICH, IDF, SBS and MS. Further, such research should compare the influence of canopy closure with different conifer species such as lodgepole pine, Engelmann spruce, Douglas-fir, white spruce and subalpine fir, on the productivity and longevity of seeded forage plants.

The rate of natural revegetation on harvested forest sites is dependent on the degree of site disturbance and compaction, the species and residual biomass of resident plants, the ingress of wind-dispersed weeds, the introduction of domestic grasses and legumes, the influence of variable climatic factors and the silvicultural activities of forest managers. Generally, recolonization by native vegetation is relatively slow and the subsequent community is often comprised of species with low forage or erosion control value. It has been estimated to take four or more years in the Pacific Northwest for indigenous plants to reoccupy denuded ground.

Initially, wind-dispersed annual weeds may dominate the plant cover, particularly on heavily disturbed sites. Although these species impose little competitive stress to tree seedlings, they may soon be replaced by aggressive perennial herbs and shrubs which are considerably more detrimental to conifer growth.

Thus, in the absence of grass/legume seeding, the resultant native plant community may: (1) leave the disturbed soil vulnerable to soil erosion for several years, (2) provide little or no forage for livestock or wildlife, and (3) compete with tree seedlings for available soil moisture or other resources in later years. The question which therefore must be addressed by the forest range manager is not whether seeded domestic grasses compete with tree seedlings, but whether competition from introduced species is of greater severity than that imposed by native vegetation. It must be realized, however, that this problem must be viewed in light of the benefits derived from seeding, such as forage production and erosion control. Long-term comparative analyses of conifer survival and growth, forage yields and erosion potential under under both successional pathways is necessary to answer this question.

3.3 Livestock Grazing in Post-Harvest Forest Communities

One of the main reasons for seeding clearcuts and forest burns is to provide a short-term forage supply for livestock. In much of the Pacific Northwest, including many parts of British Columbia, these areas serve as important, though transient, sources of summer range and are often incorporated into grazing plans directing seasonal cattle movements.

The objective of livestock management on logged sites seeded to grass and restocked with trees is to protect both the forage resource and tree regeneration while simultaneously encouraging use of the forage. Overutilization depletes domestic and native pasturage; trampling and browsing damages conifer seedlings.

3.3.1 Range Management in Clearcuts

The principles governing proper range use include (1) stocking with the right kind of animal, (2) balancing numbers of animals with forage resources, (3) grazing at the correct season of the year, and (4) obtaining optimal distribution of livestock over the range unit (Stoddart et al. 1975).

In British Columbia, seeded clearcuts are grazed by cows with calves, yearling steers or heifers. Stocking rates are presumably based on the production and availability of forage on the range unit. The start and duration of the seasonal grazing period is normally planned to coincide with the optimal stage(s) of plant phenological development, although the needs of the range user may sometimes dictate early entry. Similarly, proper animal distribution throughout the grazing period is essential to prevent localized overgrazing and to ensure uniform utilization of the available pasturage, but the degree of management required for proper use of clearcut range is often lacking.

3.3.1.1 Forage Production

The calculation of stocking rates requires accurate assessment of the amount and type of forage available on a range site. Productivity of native herbs and shrubs is considerably higher on cleared forest range than under a tree canopy. However, total forage yields can be increased dramatically with the introduction of adapted domestic grasses and legumes.

In British Columbia, McLean and Clark (1980) found that seeded clearcut blocks near Kamloops furnished two to four times more herbage than adjacent unseeded blocks. Pringle and McLean (1962) provided some indication of the magnitude of variation in forage yields between seeded and unseeded forest range in southern British Columbia (Table 24).

TABLE 24. Average forage yields (1960–1961) from seeded and non-seeded forest range at Aspen Grove, British Columbia (Pringle and McLean 1962)

Type of Disturbance	Elevation (m)	Year seeded	Yield (kg/ha)	Type of Plant Cover
Logged	1067	1956	3,403	Timothy, orchardgrass
Burned	1067	1956	3,382	Timothy, orchardgrass
Burned	1098	Not seeded	1,274	Pinegrass
Not disturbed	1098	Not seeded	499	Pinegrass

Primary productivity is a function of climatic and edaphic variability as well as biotic potential. No information is available in British Columbia comparing the productivity of seeded forages in different biogeoclimatic zones and subzones. However, Smith and Wass (1976) found that native vegetative cover three to five years after logging in the Nelson Forest Region of southeastern British Columbia was 71.6%, 59.6% and 65.5% for unburned clearcut sites in the IDF, ICH and ESSF zones, respectively. Biomass and productivity were not measured.

Estimates of the duration of grazing benefits from seeded clearcuts and burns in British Columbia vary from 8–10 years (B.C. Min. For. 1980), 14–18 years (Select Standing Committee on Agriculture 1979) to 20 years (McLean and Clark 1980). These values depend on the influences of soils, climate, shrub and tree species and their rates of regeneration, degree of forage utilization by livestock and wildlife, and silvicultural or range management treatments on the native and/or seeded forage species occupying a given site. Unfortunately, there have been no systematic, quantitative studies of how these factors interrelate over time to reduce forage yields on seeded forest range in British Columbia. Likewise, detailed studies of the composition, productivity and longevity of native forages on unseeded clearcut range in the BWBS, ESSF, ICH, IDF, MS and SBS zones are lacking.

Slightly more information is available outside of British Columbia, particularly from the American Pacific Northwest. As in the British Columbia studies, primary productivity of herbaceous vegetation increased following total removal of the overstory. For example, forage production in mixed coniferous forests of northeastern Oregon was found to rise ten to twenty-fold after clearcutting and sowing to grass (Hedrick et al. 1971; Vavra et al. 1980).

Productivity of seeded plants has been shown to vary with the environmental or biogeoclimatic conditions associated with diverse habitats. For example, Miller and Krueger (1976) studied the production potential of three different habitat types in northeast Oregon which had been cleared of ponderosa pine and Douglas-fir, burned and seeded to timothy, orchardgrass, blue wildrye, tall oatgrass, smooth brome and white clover. The habitat types, as defined by Daubenmire (1952) and Daubenmire and Daubenmire (1968), were ponderosa pine/snowberry, Douglas-fir/ninebark and grand fir/pachistima. They were situated along a soil moisture gradient from dry to wet in the order listed.

Miller and Krueger (1976) found that the grand fir/pachistima habitat type had the most potential for growing domestic forage. It had greater moisture availability and less competition from previously established species than the other two sites. Many of the understory species growing on the site prior to logging, such as adenocaulon, twinflower and western meadowrue, were adapted to dense shade. However, these plants had low population densities and, with the removal of the overstory, were unable to compete with the introduced grasses. The latter were found to constitute 69% of the primary production on this site three years after seeding (Miller and Krueger 1976).

In comparison, Miller and Krueger (1976) reported that seeded species, mainly timothy, furnished only 18% of the total vegetative production on the relatively xeric ponderosa pine/snowberry habitat type after 3 years. Seeded plants were found to comprise 33% of the total production on the moister Douglas-fir/ninebark type during the same time period, with timothy and orchardgrass accounting for 28% (Miller and Krueger 1976).

Seeded clearcuts are generally expected to remain useful as summer range for a period of up to 20 years throughout the Pacific Northwest (Table 25). Krueger (1983) summarized research on a forest plantation in northeast Oregon which had been experimentally grazed for 20 years. He showed that forage yield was reduced by about 40% through dual grazing by cattle and big game for the first 10 years. Over the second decade, shrub development was found to be the major factor reducing forage production. The negative impact of tree canopy closure on understory yields did not become pronounced until about the 18th year. Overall, herbaceous production decreased from an average of approximately 1570 kg/ha in 1965 to 750 kg/ha by 1982 (Krueger 1983).

TABLE 25. Estimated duration of grazing use on seeded clearcuts following logging in the Pacific Northwest

Location	Dominant Tree Species	Use (yrs)	Source
Montana	Lodgepole pine	20	Basile & Jensen (1971)
Southern B.C.	Lodgepole pine, Engelmann spruce	20	McLean & Clark (1980)
NE Oregon	Grand fir, Douglas-fir, Ponderosa pine	20	Krueger (1983)
NE Oregon	Grand fir, Douglas-fir, Ponderosa pine	15–20	Hedrick (1975)
Northern B.C.	White spruce	8–10	B.C. Min. For. (1980)

3.3.1.2 Cattle Production

Livestock production is a major goal of the range manager. Management practices seek to attain the most efficient transfer of energy from primary to secondary production in range ecosystems (Stoddart et al. 1975). This involves the optimization of cattle weight gains.

Representative figures for cattle gains on clearcut pastures have been reported from various locations throughout the Pacific Northwest. It is difficult to compare average daily weight gains from different sources since these values depend on several factors including: (1) the age, breed, class and stocking density of the grazing animals, (2) the species composition, abundance, availability, palatability and nutritional quality of the forage plants and (3) the length or portion of the grazing season over which the daily gains are averaged. However, some comparisons can be made.

In southern British Columbia, McLean and Clark (1980) pastured cows and calves on a seeded lodgepole pine/Engelmann spruce clearcut for 3 to 4 months, annually, over a 4 year period. Average stocking rate was 0.73 ha/AUM. Turnout occurred in early July and grazing on a 3 pasture rotation was implemented until mid-October. Each pasture was utilized for approximately 30 days a year.

The average daily gains over the four year period were found to be 0.64 kg for calves and 0.13 for cows (McLean and Clark 1980). Utilization varied from 75 to 85%, and the clearcuts were estimated to have returned about 60 kg of beef/ha/yr.

These figures can be compared with returns of 56 kg/ha/yr for yearling heifers on a seeded grand fir/Douglas-fir/ponderosa pine clearcut in northeast Oregon (Hedrick 1975). Average daily weight gains on this site ranged from 0.64 kg in exclosures permitting only cattle use to 0.84 kg where use included deer and elk as well as cattle.

Vavra et al. (1980) carried out a related study on a similar site in the mixed coniferous forest of northeast Oregon. Two clearcut pastures were grazed at a stocking density of 5 yearling steers per 2 ha from mid-July to mid-August over a two year period. Big game were excluded from one pasture; the other was grazed in common by cattle and wildlife.

It was observed that where big game were prohibited from browsing, shrub density increased about 15-fold. This, in turn, resulted in reduced forage production, inferior cattle diet quality and lowered cattle weight gains (Vavra et al. 1980). Unfortunately, no actual data were given which contrasted daily gains between pastures. However, average daily gains for both pastures varied from 0.9 kg in the first year to 0.57 kg in the second when turnout was delayed by a week (Vavra et al. 1980).

These figures compared favourably with average daily gains by yearling steers over a five year period of 0.79 kg on a ponderosa pine/Douglas-fir forest range and of 0.47 kg on a bluebunch wheatgrass/Sandberg's bluegrass range in the Blue Mountains of eastern Oregon (Holechek et al. 1981; Vavra 1983). Although the grazing season in this particular study extended from mid-June to mid-October, the gains presented above were calculated only for the portion between mid-July and mid-August to be consistent with values determined by Vavra et al. (1980).

Analysis of cattle diet quality by Holechek et al (1981) showed that preferred species in the forest contained more crude protein during the summer grazing period than on the grassland. The higher gains on forest range were therefore attributed to nutritionally superior diets (Holechek et al. 1981; Vavra 1983).

TABLE 26. Improvement in livestock carrying capacity through clearcut logging and seeding of forest range in Oregon (Vavra 1983)

Grazing period (month)	Carrying Capacity (heifer-unit-days)[1] 1980 Unlogged	1980 Logged/Seeded	1981 Unlogged	1981 Logged/Seeded
June	8.2	43.7	12.5	34.1
July	12.4	231.7	13.2	83.8
August	25.2	230.6	16.6	144.3
September	42.9	153.4	26.6	100.9

[1] Calculated on the basis of crude protein available in forage.

Increased forage production on clearcut logged and seeded forest range has been demonstrated to improve livestock carrying capacity and the potential for increased cattle production (Table 26). However, it has also been shown that the abundance and variety of forage available in clearcuts and forest burns may attract big game as well as cattle (Pearson 1968; Edgerton 1971; Kruse 1972; Patton 1976; Davis 1977; Ffolliott et al. 1977a; Regelin and Wallmo 1978). This introduces the possibility of resource conflicts between livestock producers and wildlife managers. Although exploration of this question is beyond the scope of the present review, it should be pointed out that the controversy has generally focussed on forage and spatial competition among deer, elk, wild sheep and cattle on forest range. Studies relevant to the discussion include Reynolds (1966a; 1966c), Skovlin et al. (1968; 1970; 1976), Krueger and Winward (1974), Dealy (1975), Ffolliott et al. (1977a) and Miller et al. (1981). Useful reviews of ecological overlap and interrelationships between cattle and wild ungulates in British Columbia are found in Miltimore (1972) and Pitt (1982).

3.3.1.3 Forage/Livestock Interactions

Utilization of vegetation by herbivores is a reflection of the relative palatability and availability of the forage (Heady 1964). Grazing patterns and degree of forage utilization on logged forest range may be greatly influenced by the presence of slash, amount and distribution of introduced and native forages species comprising the cattle diets, stocking density and length of the grazing period.

Logging debris may affect both the production and accessibility of forage for livestock and wildlife. On lodgepole pine clearcuts in southern British Columbia, Hoyles (1977) noted that cover of timothy, orchardgrass, smooth brome and pinegrass appeared to be inversely related to the amount of slash remaining on the site. However, the relationship was not statistically significant.

In a selectively-cut ponderosa pine forest in northern Arizona, Reynolds (1966b) found that slash covered 6.8% of the ground where undisturbed and only 3.2% where cleared. Slash cleanup had no measurable effect on production of understory vegetation, which was estimated to be 30 kg/ha on the undisturbed site and 32 kg/ha on the treated site. However, cattle use was found to be significantly less on the undisturbed area. Pellet group droppings averaged 0.46/m^2 where slash was cleared and 0.17/m^2 where it remained (Reynolds 1966b).

Likewise, Edgerton (1971) noted that plants growing along skidtrails and in other open areas were heavily used, while those growing through slash or adjacent to cull logs were lightly used by cattle on a ponderosa pine plantation in Oregon.

3.3.1.3.1 Cattle Diets and Forage Utilization

In general, seeded domestic forages appear to be favoured by cattle over native vegetation on disturbed forest range. For example, Clark and McLean (1974) observed that utilization of forage by cows on lodgepole pine and Engelmann spruce clearcuts in the IDF and MS zones of southern British Columbia was much greater on areas sown to timothy, orchardgrass and smooth brome than on unsown areas. Utilization was estimated to be 34% on the seeded field and only 8% on the unseeded control. However, individual species preferences and utilization were not measured. Related work in other biogeoclimatic zones of British Columbia with different seed mixes is lacking.

Common native forages with medium to high grazing values in the PPBG zone of B.C. include bluebunch wheatgrass, pinegrass, serviceberry and rose (McLean et al. 1964; McLean and Willms 1977; McLean 1979b). Pinegrass, aster, vetch, peavine, milkvetch, serviceberry, rose, snowberry, spiraea and willow are palatable species in the IDF and SBS (McLean and Tisdale 1960; McLean et al. 1964; McLean 1979b). Pinegrass is common on lodgepole pine sites in the ESSF and MS, while shrubs such as wild raspberry tend to dominate areas cleared of spruce and fir in these zones (McLean and Tisdale 1960; McLean 1979b). Bluejoint, hairy wildrye, slender wheatgrass, peavine, vetch, aster, rose, serviceberry and willow are abundant forage plants on trembling aspen forest range in the BWBS zone (McLean 1979b). However, no published data were found which explicitly described cattle diet preferences for these native forages.

In northeast Oregon, Miller and Krueger (1976) studied forage utilization and cattle diets on clearcut logged, forested and bunchgrass summer range (Table 27). The clearcut was seeded to timothy, orchardgrass, blue wildrye, tall oatgrass, smooth brome and white clover. Kentucky bluegrass had been established prior to logging. Eight plant communities were identified and compared (Table 27).

TABLE 27. Forage consumed by cattle on bunchgrass, forest and clearcut summer range (July 31–September 12) in northeastern Oregon (Miller and Krueger 1976).

Plant Communities	Utilization (kg/ha)	% Forage Consumed		
		Grasses	Forbs	Browse
Bunchgrass				
Sandberg's bluegrass/Kellog onion	70.7	10	0	0
Ponderosa pine/bluebunch wheatgrass	46.0	18	0	1
Forest				
Ponderosa pine/snowberry	22.5	3	0	1
Douglas-fir/snowberry	9.0	3	0	1
Grand fir/adenocaulon	4.5	0	0	0
Clearcut				
Kentucky bluegrass/goatsbeard	62.9	9	0	0
Ninebark/timothy	70.7	18	0	1
Timothy/orchardgrass	234.7	34	1	0
Totals	**521.0**	**95**	**1**	**4**

The heaviest levels of utilization by cattle occurred in the seeded clearcut and, in particular, the timothy/orchardgrass community (Table 27). The three plant communities on the logged site provided 63% of the forage consumed, yet only accounted for 31% of the study area (Miller and Krueger 1976). Seeded grasses contributed 55% of the cattle diet. Of these, orchardgrass was the most preferred, accounting for 28% of the diet, followed by timothy (16%), tall oatgrass (6%), blue wildrye (4%) and smooth brome (1%). Miller and Krueger (1976) assigned relative preference indices of 2.4, 1.7, 1.5, 2.3 and 0.7 to these five species, respectively, based on a species' frequency of occurrence in the animals' diet in relation to its frequency of occurrence on the range.

In another study in northeast Oregon, a 12 ha stand of mixed coniferous forest was clearcut in 1963 and broadcast burned a year later (Krueger 1983). Three 2 ha experimental pastures were constructed and half-sown to timothy, orchardgrass, smooth brome and tall oatgrass. The remaining half was left as an unseeded control.

Orchardgrass was found to be the most heavily grazed plant, with an average utilization by cattle of about 55% (Krueger 1983). The remaining seeded grasses, as well as elk sedge, pinegrass, western fescue, tall trisetum and Kentucky bluegrass, were utilized at slightly lower levels ranging from 40–50%. None of the dominant forbs, such as western yarrow, Canada milk-vetch, bull thistle and strawberry, were grazed to any great extent by the cattle.

Studies by Vavra et al. (1980) on cattle diets in the same clearcut pastures in 1972 and 1973, using fistulated steers, indicated that herbaceous vegetation accounted for about 75% of the forage consumed, except during a dry period when it declined to 55%. Graminoids comprised 45–65% of the cattle diets, while forbs contributed about 10% and shrubs made up the balance.

Cattle diets are a function of animal preference and selection. In seeded clearcuts, cultivated plant species normally make up a larger proportion of the vegetation than natives, and are more heavily utilized. Gesshe and Walton (1981) examined the preferences of steers offered a variety of cultivated forages, including smooth bromegrass, creeping red fescue, crested wheatgrass, intermediate wheatgrass, redtop, Russian wildrye, alfalfa, birdsfoot trefoil, sainfoin and white clover in east-central Alberta.

When sampled in the vegetative stage during May and June, differences in preference were found to be small (Gesshe and Walton 1981). However, preferences were more pronounced after seed set. During this period creeping red fescue, crested wheatgrass, intermediate wheatgrass and sainfoin were rejected. Relative preference ratings for the remaining grasses were 1.7, 1.5 and 1.2 for Russian wildrye, redtop and smooth brome, respectively. Preferred forbs were birdsfoot trefoil, white clover and alfalfa with ratings of 1.9, 1.6 and 1.3, respectively.

Gesshe and Walton (1981) developed a significant multiple regression equation relating various forage quality factors to preference ratings of selected plant species. Simple correlation coefficients indicated that percentages of leaves, stems, crude fibre and of stem acid-pepsin dry matter disappearance had a positive influence on the preferred rating for these cultivated species. Leaf and stem protein decreased animal preference. Late in the grazing season, moisture content was also found to significantly affect preference. Gesshe and Walton (1981) concluded from these data that forage quality was important in determining preference for cultivated grasses and legumes.

3.3.1.3.2 Impact of Grazing on the Plant Community

Cattle grazing influences the species composition, distribution and abundance of forage plants over time in seeded clearcuts. The term "range condition trend" refers to the direction of change in forage composition and productivity on a range site, normally in response to grazing. However, on logged forest range the successional effects due to competition from native herbs and shrubs and to the developing tree overstory confound effects due to the grazing factor alone by engendering an apparent "downward trend" in range condition unrelated to livestock utilization (Hall 1978).

Long-term data on vegetative changes within seeded clearcuts in British Columbia, and interpretation of these trends in relation to grazing, competition and canopy cover, are presently unavailable. Pitt (1983) suggested that the objective of grazing management on clearcuts may be to utilize this new forage resource completely over a short period of time. Under such a scenario quantification of range condition and trend may be disregarded. However, he went on to state that there was still a need to develop range condition guidelines relevant to the diverse forest ecosystems in British Columbia, including clearcuts. These guidelines should describe seral stage, forage composition and productivity, appropriate stocking rates and season of use to permit proper utilization of the herbage produced on forest range (Pitt 1983).

It is uncertain from published literature outside of this province how important cattle grazing is in the overall dynamics of successional plant communities on harvested forest range. In a study concerning the impacts of selective logging and grazing on a mixed coniferous forest in Oregon, Krueger and Winward (1976) pointed out that the residual effects of logging had more total influence on community structure than big game browsing and cattle grazing.

It is evident that cattle diet preferences will selectively modify the composition of plant communities. Hall (1975) reported that seeded grasses will be largely replaced by native graminoids in 15 to 20 years under good livestock management after regeneration cutting in the mixed conifer/pinegrass community type of eastern Oregon and Washington. However, he further stated that under heavy use domestic grasses will decrease more rapidly because of their greater palatability than native species, causing a negative trend in range condition. Nevertheless, the literature has generally indicated that even highly preferred species such as orchardgrass, timothy and smooth brome may persist in successional forest range communities in appreciable numbers for 10 years or more (Wilson 1949; Lyon 1976; Krueger 1983).

Krueger et al. (1980) found that big game browsing on shrubs had more influence on succession than cattle grazing 14 years after timber harvest on a mixed coniferous forest site in northeast Oregon. In a pasture restricted to cattle use only, shrub densities were higher and herbaceous forage frequencies lower than on an adjacent pasture grazed by both cattle and big game. Krueger et al. (1980) suggested that the suppression of the herbs, mainly mountain brome, pinegrass, blue wildrye, western fescue, western yarrow, Nevada peavine, elk sedge, Ross sedge and northwest sedge, was caused by shrub competition rather than cattle grazing. Browsing of shrubs by big game in the dual grazing situation reduced plant competition and maintained herbage production (Krueger et al. 1980).

Wildlife also affect plant succession on disturbed forest range through selective consumption of seeded and native herbs. Timothy, tall oatgrass, blue wildrye and smooth brome were found to account for 36% of deer and elk diets on clearcuts and forested ponderosa pine range in northeastern Oregon (Miller et al. 1981). Native forbs in the clearcut community made up 38% of the big game diet. Goatsbeard was the most preferred forb, comprising 25% of the diet (Miller et al. 1981).

Use of sown forages by wildlife may occur even before seed germination and seedling establishment can take place. For example, seed predation by mice has been observed to influence the outcome of range seeding projects (Howard 1950; Johnson 1961; Sullivan and Sullivan 1982b). Evanko (1953b) found that a number of pasture species planted on lodgepole pine burns in northeast Washington were heavily used by rabbits and deer soon after seedling emergence, especially alsike clover and yellow sweetclover. Dyrness (1967) reported that seedlings of white Dutch clover were highly palatable to deer, and that concentrated utilization of this legume has led to poor survival in many roadside stabilization seedings in the Pacific Northwest.

Krueger (1983) presented results from a 20 year study of forest grazing on a ponderosa pine/Douglas-fir/western larch/western white pine plantation in northeastern Oregon. His general conclusions were that cattle and big game grazing had their greatest impact on the plant community and secondary succession during the first ten years after clearcutting. Subsequently, shrub and tree growth dominated the distribution and abundance of herbaceous forage species (Krueger 1983).

3.3.1.4 Cattle Management to Improve Utilization

As pointed out earlier, the objectives of cattle management are to optimize weight gains, yet simultaneously perpetuate the forage resource (Heady 1975; Stoddart et al. 1975). This may be accomplished by regulating the season of use, cattle distribution and cattle numbers.

Assessing the proper season of use depends on the phenological development and physiological state of key forage species. Reid (1979) pointed out that these key or indicator plants should be highly palatable and comprise more than 15% of the usable forage. On seeded clearcuts, indicator species for both range readiness and proper use may be one or more of the introduced grasses and legumes, but can also include dominant native forages such as pinegrass.

In southern British Columbia, it was found that domestic grasses such as timothy and orchardgrass developed faster in the spring than pinegrass on seeded lodgepole pine/Engelmann spruce clearcuts (Clark and McLean 1978; McLean and Clark 1980). These authors recommended that such areas sown to timothy and orchardgrass should be grazed early in the season to optimize utilization of the two introduced species. Since it was observed that orchardgrass produced good regrowth in the fall, they further suggested that forest ranges containing this species may be grazed again in autumn (Clark and McLean 1978; McLean and Clark 1980).

McLean and Clark (1980) reported that where the grazing period was too long on conifer plantations near Kamloops, British Columbia, the forage was severely overutilized. Therefore, they recommended that clearcuts should be grazed for only short periods of time and, if a series of adjacent clearcuts were available, systematically grazed over the season on a rotational basis (McLean and Clark 1980).

Similar findings and recommendations have been published in the literature outside of British Columbia. Improved utilization of orchardgrass, timothy, tall oatgrass and smooth brome, as well as higher weight gains by yearling heifers, were obtained on a mixed conifer clearcut in northeast Oregon by turning out the cattle from late June to mid-July (Krueger 1983; Vavra et al. 1980). The seeded grasses were most palatable during this stage in the growing season (Krueger 1983).

Hedrick (1975) pointed out that since seeded clearcuts were so valuable for timber and range, they should be managed as key areas within larger grazing units. He recommended that logged and seeded grand fir sites in Oregon should be stocked with cows and calves during the early part of the growing season until utilization reached about 60% of current annual growth. At this point, the cattle should be removed to allow plants to replenish their carbohydrate reserves (Hedrick 1975). By late summer, seeded plants were generally dormant on these sites and not expected to be damaged by grazing. Thus, Hedrick (1975) suggested that cows could be returned after weaning and kept on the range unit until proper use had been reached overall.

Miller and Krueger (1976) advocated similar management techniques, suggesting that coordinated planning of clearcut harvesting and forage seeding activities may increase utilization of less preferred forest communities adjacent to seeded clearcuts. It was pointed out that a great deal of flexibility in grazing programs could be developed, and more uniform utilization of diverse plant communities could be attained, by locating clearcuts strategically within larger grazing units (Miller and Krueger 1976).

Improved use of available forage resources may also be achieved through manipulation of livestock distribution and numbers, in addition to season of use. Standard management techniques for regulating cattle distribution include fencing, water developments, salting, construction of driftways or access routes and range riding (Skovlin 1965; Wood 1972). Fencing is an effective, though costly, means of managing cattle movements. However, Mitchell et al. (1982) suggested that animal distribution on clearcut pastures can be controlled to a certain degree by inexpensive, natural barriers fabricated from cull logs.

Determination of stocking densities requires a detailed knowledge of seasonal forage production and grazing capacity. McLean and Marchand (1968) indicated that an average of about 300 kg of available forage is needed per animal unit month (AUM). Available forage on grasslands may be calculated from estimated total forage yields by allowing a 45% carryover to avoid damage to the range (McLean and Marchand 1968). However, the applicability of this procedure has not been demonstrated on clearcut forest range.

3.3.2 Tree/Livestock Interactions

In timbered areas where grazing is permitted, livestock are frequently held responsible for any observed damage to tree reproduction simply because these animals are clearly visible. However, young trees on forest range also suffer injury from fungal organisms and invertebrate pests (Lewis et al. 1972), small mammals (Sullivan and Sullivan 1982a), and big game (Crouch 1969; Harper 1969). Unfortunately, very little quantitative data are presently available which accurately compare the relative importance and long-term effects of damage to tree seedlings from these various agents, including cattle.

3.3.2.1 Characteristics and Effects of Animal Damage

Livestock and wildlife can adversely affect tree regeneration through defoliation, girdling, browsing and trampling of seedlings. Cattle generally do most harm by trampling and sheep by browsing (Adams 1975). Wildlife injuries are commonly associated with browsing (Crouch 1969; Harper 1969) and girdling (Sullivan and Sullivan 1982a).

Studies investigating the impact of cattle grazing on lodgepole pine and Engelmann spruce survival and growth have been conducted over an eight year period on several clearcuts in the IDF and MS zones of southern British Columbia (Clark and McLean 1978; McLean and Clark 1980). General conclusions derived from this research were that damage was a result of repeated trampling rather than browsing. The proportion of total mortality attributable to cattle ranged from 20 to 56%, with the remainder due to rodents and natural causes (McLean and Clark 1980). It was also observed that both the highest and lowest mortality due to cattle occurred on nonseeded areas, suggesting that density of herbage was not necessarily a factor in cattle damage to coniferous regeneration (McLean and Clark 1980).

Comparable results have been reported from pine forests in the west and southeast United States. For example, browsing damage by cattle on a ponderosa pine plantation in Oregon was found to be small over the summer grazing season (Edgerton 1971). This was attributed to turnout of livestock in late spring when an abundance of preferred herbaceous forage was already available, and to cattle removal by mid-summer before the forage had become depleted or unpalatable. Where browsing of pines did occur, usually only the tips of a few needles were clipped. Occasionally, however, the terminal buds were broken off causing laterals to assume dominance. This type of injury was found most often along well travelled skid trails and resulted more frequently from trampling than browsing (Edgerton 1971).

In central Colorado, Currie et al. (1978) found that heavy summer use (over 50% forage utilization) of a ponderosa pine plantation resulted in browsing wounds to 83% of the tree seedlings. Damage was much less with moderate (30–40% utilization) and light (10–20%) grazing rates, and it was generally observed that most injury and mortality of naturally established seedlings and planted nursery stock came from causes other than cattle. Pines subjected to recurrent browsing were found to suffer damage to both lateral and terminal buds. Such seedlings frequently survived, but were hedged or otherwise deformed (Currie et al. 1978). However, studies in Arizona have shown that deformed ponderosa pine seedlings released from recurrent browsing generally attained normal configuration and vigour within a few years after cessation of browsing (Heerwagen 1954).

In central Louisiana, Cassady et al. (1955) concluded that cattle rarely grazed longleaf, loblolly, or slash pine foliage when other green forage was available, although browsing of pine seedlings increased where desirable green herbs were limited in variety or quantity. Similarly, Pearson (1974) reported that once green herbage became plentiful, browsing of slash pine virtually ceased on grazed plantations in the Palustris Experimental Forest, Louisiana. Pearson (1971) noted that neither light nor moderate grazing by cattle (33 and 47% utilization) over a 5-year period affected establishment or survival of seeded and planted slash pine. Heavy grazing (56% utilization) resulted in slightly fewer pines per hectare, but the losses were fairly uniformly distributed throughout the stands and did not significantly reduce tree stocking densities.

Seedling losses from trampling are greatest where cattle concentrate and overgraze. It was noted in Louisiana that most slash pine mortality from trampling occurred during the first year after planting and the first two years after seeding (Pearson 1974). However, by the time tree seedlings reach 0.5 to 2.0 m in height on southern pine plantations, mechanical injury due to rubbing is more prevalent than that due to trampling (Cassady et al. 1955; Lewis et al. 1972).

Conifer species apparently vary in their tolerance to browsing and trampling damage. For example, Lewis (1980a; b; c) experimentally studied the effects of girdling, browsing, trampling and defoliation on the survival and growth of slash pine seedlings. He concluded that this species was quite resistant to damage and able to withstand extreme forms and intensities of injury. In contrast, it was found that container-grown Douglas-fir seedlings were very susceptible to trampling damage during their first year after planting in northern Idaho (Eissenstat 1980; Eissenstat et al. 1982).

The browsing of pine foliage may have undesirable impacts on cattle health and physiology. For instance, ingestion of ponderosa pine needles is believed to cause abortions in pregnant cows wintered on forest range in the northern United States (MacDonald 1952; Thompson and Gartner 1971). However, studies by Majak et al. (1977) in British Columbia revealed that a water extract of ponderosa pine needles experimentally administered to pregnant cattle produced no ill effects and normal calves were delivered.

3.3.2.2 Silvicultural Benefits from Cattle Grazing

Livestock grazing may enhance conifer survival and growth in some circumstances. Many clearcuts grazed by cattle in southern British Columbia can become overstocked with naturally regenerated lodgepole pine. In these situations, cattle-induced mortality of pine seedlings may actually be beneficial by lowering tree densities to acceptable levels. For example, McLean and Clark (1980) reported that on four clearcut study areas in the IDF biogeoclimatic zone, stocking levels of natural lodgepole pine regeneration were 3880, 1705, 3052 and 5609 stems/ha. The percentages of total mortality due to cattle on these sites were 46%, 29%, 49% and 56%, respectively. Since the ideal stocking rate for this forest type is considered to be 1100 to 1500 well-distributed stems/ha, the authors concluded that even high degrees of cattle damage did not prevent adequate tree stocking levels (McLean and Clark 1980). Such "natural thinning" is generally thought, but has not been shown, to be non-selective.

Similarly, competition to conifer seedlings from forage plants can be decreased through livestock grazing and browsing. Hedrick and Keniston (1966) reported that removal of palatable herbage by sheep on a Douglas-fir plantation in Oregon increased available soil moisture and positively influenced height growth of the conifer seedlings. In a later study, in the Siuslaw National Forest in western Oregon, the grazing of sheep on clearcuts for carefully timed intervals during mid to late summer was found to reduce brush competition with Douglas-fir seedlings (Richmond 1983). Brush density was lower in the grazed areas compared to the adjacent ungrazed enclosures, and the diameter growth of trees on the grazed site was 7–14% greater than on the ungrazed control areas.

Cattle grazing on radiata pine plantations in New Zealand has been shown to control native woody growth, bracken and coarse grasses, but the effect of decreased competition on tree growth was not investigated (Beveridge et al. 1973). In California, Kosco and Bartolome (1983) found a significant reduction in total shrub cover on a clearcut planted to Douglas-fir and ponderosa pine when grazed by cattle. However, no significant difference in average tree height between grazed and ungrazed treatments for either species was noted two years after planting. Continued monitoring may be expected to reveal differences as the trees and brush mature, but the authors pointed out that the generally poor quality planting stock used in the experiment could preclude definite conclusions about the long-term relationship between conifer seedlings and brush density.

Edgerton (1971) stated that five years of cattle, deer and elk grazing had neither benefitted nor significantly harmed average ponderosa pine growth on a planted clearcut in Oregon. However, in a synthesis of 20 years of research on forest grazing in the mixed coniferous forest of northeast Oregon, Krueger (1983) indicated that a clearcut pasture grazed by cattle and big game had greater height growth of Douglas-fir and ponderosa pine than a pasture protected from cattle grazing.

Grazing may create suitable seedbed conditions for conifer germination. For example, it was found in central Washington that livestock grazed down the heavy cover of native pinegrass under relatively open stands of virgin ponderosa pine and produced an environment favourable for tree seedling establishment (Rummell 1951). On ungrazed sites, pine regeneration was negligible (Rummell 1951).

3.3.2.3 Cattle Management to Control Damage

Studies in the southern interior of British Columbia have shown that where extensive cattle damage has occurred on lodgepole pine/Engelmann spruce plantations, poor cattle management was usually to blame (Clark and McLean 1978; McLean and Clark 1980). In such cases, the period of grazing was prolonged, resulting in overutilization of forage and considerable trampling damage to coniferous seedlings. The authors concluded that numbers of cattle and length of grazing must be rigidly controlled to minimize damage to trees (Clark and McLean 1978; McLean and Clark 1980). They stressed that clearcuts should be intensively grazed for only short periods of time and, given a sufficient number of seeded cutblocks, grazing should be on a rotational basis.

Likewise, Edgerton (1971) pointed out that under proper management, which gave due consideration to stocking rate and season of use, cattle could be compatible with reforestation practices in mixed coniferous forest clearcuts in northeastern Oregon and southeastern Washington. Grazing damage was light in his study because the cattle were removed before the forage was depleted or had become coarse and relatively unpalatable (Edgerton 1971).

Based on considerable research dealing with cattle grazing in the mixed coniferous forests of eastern Oregon, Wheeler et al. (1980) concluded that survival and growth of planted timber species and livestock could be compatible if:

(1) entry and removal of cattle were accomplished at the proper time with regard to the phenological stage of both forages and trees;
(2) provision was made for the dispersal of grazing animals through fencing or riding, and strategic location of salt and water; and
(3) preferred forage species, seeded and/or native, were available in reasonable abundance.

Monfore (1983) reported that cattle could be used to control herbs and shrubs within ponderosa pine and lodgepole pine plantations in eastern Oregon. However, he pointed out that strict livestock management was required to protect the pine seedlings. He suggested:

(1) very early turnout, prior to bud break, to prevent grazing of the tender annual growth on tree seedlings;
(2) herd control through riders to keep the animals well distributed on the plantation to ensure even cropping of the forage;
(3) high cattle stocking densities to assist in obtaining uniform forage utilization; and
(4) water developments.

Currie et al. (1978) concluded on the basis of studies with ponderosa pine in central Colorado that protection of natural and aritificial pine regeneration from cattle grazing was not necessary provided that grazing intensity was prescribed to use 40% or less of the principal grasses, the forested ranges were in fair to good condition and adequate water supplies were available.

In the northwestern United States, Hess (1966) reported that livestock grazing on privately-owned ponderosa pine/Douglas-fir forestland in Washington required intensive herd management because range use was secondary to timber production and harvesting in these areas. In a later paper, he stressed that forest companies could not afford to allow grazing damage to occur at any stage in stand development because the investment in plantation or natural regeneration efforts was substantial (Hess 1983). He pointed out that complete deferment of a grazing unit may be necessary to achieve protection of a portion, and advised strict controls on grazing leases to safeguard forestry interests. O'Connell (1983) went further, stating that livestock should be kept out of plantations and confined to areas with timber stands 15 years of age or older. Unfortunately, the most productive areas in terms of forage yields and grazing capacity are those with stands less than 15 years of age (Krueger 1981).

In the pine forests of the southern United States, it has been recommended that cattle not be allowed to graze an area intensively until slash or longleaf pine saplings were 2.0 to 3.0 m tall (Cassady et al. 1955; Lewis et al. 1972). Although Cassady et al. (1955) indicated that seedling losses from trampling were greatest during the first year after planting and the first two years after seeding, Pearson (1974) found that grazing intensities up to 49% forage utilization were compatible with slash pine regeneration in Louisiana even during the vulnerable first year. Cassady et al. (1955) advised that if grazing was permitted during the first few years after planting on these southern pine sites, it should not begin before May 1st and should be regulated so that not more than half of the green forage was utilized during the entire season.

3.3.3 Summary and Discussion

The objective of livestock management on clearcuts restocked with conifers and seeded to grass is to protect both the forage resource and tree regeneration and to produce beef. Primary productivity is significantly higher on clearcuts sown to domestic forage species than on unseeded logged sites or those under forest cover. This productivity is greatest the first few years following seeding, but declines steadily thereafter.

Estimates of the duration of the grazing resource provided by seeded and nonseeded clearcuts vary from 8 to 20 years throughout the Pacific Northwest. These values depend on the combined influence of soils, climate, shrub and tree species and their rates of regeneration, degree of utilization by livestock and wildlife, and silvicultural or range management actions on the native and/or introduced forage species occupying a given site.

Cooperative research by forest and range scientists at Oregon State University over the past 20 years has demonstrated that grazing by livestock and wildlife had the largest impact on both introduced and native forage productivity during the first 10 years after seeding on a mixed coniferous forest clearcut in eastern Oregon. Shrub competition and, later, tree canopy closure were found to have the greatest influence on forage yields over the next decade. No comparable work has been done in British Columbia or elsewhere in the Pacific Northwest, but similar cooperative efforts should be encouraged.

Effective management of clearcut forest range demands knowledge of the various factors affecting forage productivity and the interrelationships among them. Long-term research is necessary to quantify the relative importance of soil, climate, plant, animal and management factors in affecting seeded and native forage yields. Ideally, such research would compare and contrast results from several biogeoclimatic zones, including the ESSF, ICH, IDF, MS and SBS. More realistically, study sites should be limited to zones or subzones deemed critical to the ranching industry.

Average daily weight gains vary with the age, breed, class and stocking density of the grazing animals, the species composition, abundance, availability, palatability and nutritional quality of the forage plants and the length or portion of the grazing season over which the daily gains are averaged. Representative figures in the Pacific Northwest range from 0.13 kg/day for cows on seeded lodgepole pine clearcuts in British Columbia to 0.9 kg/day for yearling steers on seeded mixed conifer clearcuts in Oregon.

Grazing patterns and degree of forage utilization by cattle on clearcuts are influenced by the presence of slash, amount and distribution of introduced and native forage species, cattle stocking rates and the length of the grazing period. Logging debris tends to inhibit animal movements by creating physical barriers which discourage uniform distribution of livestock and efficient use of the available forage. Seeded forages generally appear to be preferred by cattle over native species, and selective grazing on these plants in the absence of herd control accelerates their eventual disappearance from the community. No quantitative data were found concerning cattle diets and forage preferences on clearcuts supporting only native vegetation. Similarly, information describing the impact of grazing on unseeded post-harvest plant communities is lacking.

There is a definite need to develop range condition guidelines for grazed clearcuts in British Columbia. These guidelines should specify native forage composition and productivity by biogeoclimatic zone or ecosystem association, as well as appropriate stocking rates and season of use to permit proper utilization of the grazing resource. Indicator plant species for determining range readiness and proper range use should be identified, and their biological and autecological characteristics described. The influence of seeded species on forage composition, productivity and range condition should be incorporated into the guidelines, realizing that this influence will vary depending on the seed mix, site preparation treatment, or other management activities.

Clearcuts should be managed as key areas within large grazing units. Coordinated planning of clearcut logging, forage seedings and grazing systems may improve utilization of both seeded clearcuts and adjacent, less preferred forest communities.

The grazing of clearcuts by livestock and wildlife can affect tree regeneration through the defoliation, girdling, browsing and trampling of seedlings. Research on cattle grazing in pine plantations in the southern United States and in the Pacific Northwest has demonstrated that cattle rarely graze pine foliage when other green forage is available. Most damage by cattle occurs from trampling, and this has generally been attributed to poor cattle management. The literature has consistently pointed out that overextension of the grazing season and inadequate control of cattle numbers and distribution inevitably leads to overutilization of the available forage and extensive damage to tree seedlings. Provided accurate range condition guidelines exist with recommendations for the proper use of a given clearcut, this is a management rather than a research problem.

Studies with slash pine in the southern United States have shown that this species is capable of surviving extreme forms and intensities of injury as well as rapidly recovering growth after damage. However, it is unknown whether all conifers, or even all pines, share these characteristics. Comparative research is required to assess the impact of severe physical damage to lodgepole pine, Engelmann spruce, white spruce, Douglas-fir, western larch and subalpine fir, as well as to determine their relative tolerances to such mutilation. This information would be useful in selecting conifer species to restock clearcut forest range.

Livestock grazing may sometimes perform silvicultural functions in the form of "thinning" overdense pine regeneration through trampling and by decreasing herb competition to tree seedlings through cropping. However, these assumed benefits have not been adequately demonstrated or measured in either economic or ecological terms. "Natural spacing" of dense pine stands by cattle appears to be non-selective, and decreased herb competition must be balanced against possible trampling damage. Further study is recommended to elucidate these interactions.

4 TREE/FORAGE/LIVESTOCK INTERACTIONS IN LATE SUCCESSIONAL AND CLIMAX FOREST ECOSYSTEMS

Late successional and climax forest ecosystems are characterized by the presence of tree strata. Mixed, uneven-aged stands are multi-storied, while clearcuts planted to a single tree species result in pure, even-aged stands with only one well-defined tree layer. In both cases, however, canopy closure reduces the production of forage (Moir 1966; Krueger 1981) and its utilization by cattle (Hedrick et al. 1968).

4.1 Forage Production in Stratified Forest Communities

Perhaps the single most important influence on the growth, quality and composition of herbs and shrubs in stratified forest communities is the tree overstory. Forest canopies control the development of understory plants by modifying the complex interaction of light, heat, moisture and litter accumulation at the forest floor (Krueger 1981). Thus, management of the overstory through appropriate silvicultural treatments can have a dramatic effect on forage production.

4.1.1 Tree/Forage Interactions

Numerous studies have demonstrated an inverse relationship between tree canopy cover and forage yields. Young et al. (1976b) found highly significant negative correlations when tree crown cover, tree basal area and tree stems per plot were regressed against herbage cover and yield in a Douglas-fir/ponderosa pine/grand fir forest in northeastern Oregon. Although overstory crown cover was difficult to sample objectively, it accounted for more of the variability in herbage production than either tree basal area or stem density (Young et al. 1967a).

Jameson (1967) presented a generalized growth equation relating herbage production to overstory cover for a ponderosa pine forest in southern Arizona. Negative logarithmic curves generated from this mathematical model fit the data better than either linear or polynomial regressions (Jameson 1967). However, Ffolliott and Clary (1975) found significant differences in herbage-timber relations within ponderosa pine stands on sedimentary and igneous soils in Arizona. Their results indicated that generalized estimates of herbage productivity, which do not account for soil differences, may not be sufficiently accurate for land-use planning.

Similarly, data have been published which suggest that ponderosa pine litter accumulations can affect herbaceous production and species composition independently of canopy effects (Pase 1958; Pase and Hurd 1958; McConnell and Smith 1971). Wolters (1982) and Wolters et al. (1982) noted that understory biomass on southern pine forest ranges may be influenced by a number of variables including tree species, plantation age, rate of growth, tree density, tree distribution, competing vegetation, precipitation, soils and physiographic factors. However, Wolters (1982) found through linear regression analyses that basal area alone explained 80% of the variation in herb production under longleaf pine and 71% of the variation in slash pine stands in central Louisiana.

The correlation between understory production and canopy cover on forest range has led to reasonably successful attempts to approximate herbage yields in British Columbia from aerial photograph estimates of lodgepole pine and Douglas-fir crown cover (Dodd et al. 1972). Nevertheless, in the Pacific Northwest it has been found that only recently thinned or open coniferous forests have a reliable understory/overstory relationship because most forage reduction occurs by the time canopy cover has reached 20–30% (Dodd et al. 1972; Krueger 1981).

Eddleman and McLean (1969) pointed out, on the basis of research on ponderosa pine forest range in Washington, that herbage under less than 10% canopy cover was approximately equivalent to that on adjacent open grasslands. However, production on plots with over 50% cover was so sparse that it was considered insignificant as a forage resource (Eddleman and McLean 1969).

Representative estimates of herb and shrub production under different crown cover classes for lodgepole pine and Douglas-fir in the IDF zone of southern British Columbia have been presented in Table 28. The ground cover on these sites consisted mainly of pinegrass, bearberry, wild rose, twin flower and creamy peavine (Dodd et al. 1972).

The yield, cover and vigour of understory plants may vary considerably with tree species, stem density and stand age. The figures in Table 28 suggest that production of ground vegetation was slightly higher under lodgepole pine cover than Douglas-fir. This has been corroborated by data from Tisdale (1959), who compared understory yields from aspen, lodgepole pine and Douglas-fir cover types in southern British Columbia. Although the possible confounding effects of stand age or density were not discussed by Tisdale (1950), the data showed that production was greatest under the seral hardwood canopy, less under seral lodgepole pine and least under climax Douglas-fir (Table 29).

TABLE 28. Average dry weight understory production for different canopy cover classes of lodgepole pine and Douglas-fir at Pass Lake, British Columbia (Dodd et al. 1972)

Crown Cover Class (%)	Total Understory Production (kg/ha)	
	Lodgepole Pine	Douglas-fir
0–20	850	775
20–40	715	—
40–60	515	510
60–80	440	330

TABLE 29. Dry weight biomass estimates of understory vegetation from different tree cover types in the IDF zone of southern British Columbia (Tisdale 1950)

Tree Cover Type	Understory Biomass (kg/ha)		
	Palatable	Unpalatable	Total
Aspen	698	26	724
Lodgepole pine	328	137	465
Aspen/Lodgepole pine/Douglas-fir	357	19	376
Douglas-fir	174	19	193

Similar results have been reported for aspen and ponderosa pine stands in the Black Hills of South Dakota (Table 30). Common understory species in these forest range types include Kentucky bluegrass, roughleaf ricegrass, danthonia, bearberry, clover, mahonia, creamy peavine, snowberry, serviceberry, spiraea and wild rose (Reid 1965; Kranz and Linder 1973). Tree density, canopy cover and stand age were not measured, but overstory basal areas were determined to be lowest in the subclimax aspen stands and greatest in the climax ponderosa pine forest (Kranz and Linder 1973). Conversely, total understory production was highest in the aspen stands and least under the pine canopy (Table 30).

TABLE 30. Overstory basal area and understory production for 3 forest communities in the Black Hills of South Dakota (Kranz and Linder 1973)

Forest Community	Basal Area (m^2/ha)	Understory Production			
		Shrub	Grass	Forb	Total
Aspen	21	232	225	203	660
Aspen/Pine	31	170	149	146	465
Ponderosa pine	41	173	46	64	283

Although data were not found which quantified forage yields under late successional and climax stands of white spruce, Engelmann spruce/subalpine fir or cedar/hemlock, understory herb and shrub production is considered to generally be quite low in these forest types (McLean 1979b; McLean and Holland 1958).

4.1.2 Timber Management and Forage Production

Timber management prescriptions designed to improve tree growth and stand productivity in late successional forest may act to promote forage production as an incidental benefit. The two most important silvicultural techniques in this regard are intermediate cuttings and prescribed burning.

4.1.2.1 Intermediate Cuttings

Intermediate cuttings refer to the selective removal or improvement of trees during the period between regeneration and timber harvest. They include thinning, release cutting, sanitation cutting and pruning (Smith 1962).

Perhaps the more useful of these from a range perspective is thinning, in which surplus trees are removed from a stand for the purpose of concentrating the potential wood production on a limited number of selected trees (Smith 1962). Although a major objective of thinning is to regulate the distribution of growing space for the advantage of the existing tree crop, opening up the canopy causes highly significant increases in understory vegetation (Pase and Hurd 1958; McConnell and Smith 1970). This increased production may be associated with favourable changes in light quantity, quality and intensity, as well as in temperature and moisture conditions at the ground surface and in the soil following reduction of the overstory (Krueger 1981).

Published studies investigating the effect of thinning on forage production are presently unavailable for British Columbia forest ranges. However, representative data from ponderosa and lodgepole pine stands in the American Pacific Northwest, and for slash pine forests in the southeastern United States, have been documented in the literature.

For example, 8 years after thinning a dense ponderosa pine stand in eastern Washington to spacings of approximately 4 m × 4 m (655 trees/ha), 6 m × 6m (331 trees/ha), 8 m × 8m (166 trees/ha) and unthinned (6916 trees/ha), the net average herbage yield increment due to thinning ranged from 203 kg/ha at the 4 m spacing to 384 kg/ha at the 8 m spacing (McConnell and Smith 1970). A 6.7 kg/ha increase in understory yield occurred for each 1% decrease in tree canopy cover, triple the rate of increase of 2.25 kg/ha reported 3 growing seasons after thinning (McConnell and Smith 1965).

Total understory increases 3 years after thinning were 54%, 40% and 6% for grasses, forbs and shrubs, respectively, while corresponding figures after 8 years were 51%, 37% and 12%. Although grasses had a higher rate of increase than forbs, forb yields exceeded grass yields under denser pine canopies, with 45% coverage denoting the equilibrium point (McConnell and Smith 1970).

Pase and Hurd (1958) noticed little increase in herbage produced in ponderosa pine stands in the Black Hills of South Dakota when basal area was reduced from 46 to 32 m^2/ha. However, total herbage production tended to increase more rapidly as basal area dropped below 32 m^2. Grasses made the largest gain in weight per unit area, averaging 15 kg/ha under dense pine cover and 1493 kg/ha on clearcuts. In comparison, forbs increased from 2.25 to 235 kg/ha and shrubs from 7.9 to 131 kg/ha (Pase and Hurd 1958).

In central Oregon, Dealy (1975) studied changes in the understory productivity of a 47-year-old lodgepole pine stand thinned to 5 different spacing levels. Thinning resulted in a productivity loss for the first 2 years due to shock of overstory removal. However, by the third year herb cover exceeded prethinning levels in all spacings, and after 9 years the stands were producing from 300 to 1000% more ground cover than before thinning (Dealy 1975). Unfortunately, no actual yield estimates were presented for thinning treatments versus control.

In central Louisiana, Grelen et al. (1972) thinned a seeded slash pine stand from an average of 14000 trees/ha at stand age 3 to densities of 10400, 7000, 3500, 2000, and 1200 stems/ha. At stand age 12, unthinned check plots with 9230 stems/ha produced 628 kg/ha oven-dry herbage, while plots thinned to 1200 stems/ha had over 2000 kg of herbage per hectare. Yields were intermediate at timber densities between these two extremes.

Although experimental results such as the above clearly demonstrate that thinning increases understory production, McConnell and Smith (1970) pointed out that more economical slash disposal methods had to be developed before thinning could make a practical contribution to the range resource. Cattle have been found to prefer areas cleared of slash (Reynolds 1966b), presumably because the forage was more accessible (Hedrick et al. 1968; Dealy 1975).

Apart from influencing biomass yields, reduction of tree canopy cover through thinning may also affect the nutritional quality and species composition of forage plants. Shaded plants tend to flower later than those in the open, and because of this delayed development the quality of forest herbs for grazers is often superior to that of mature plants on open range toward the end of the growing season.

For example, McEwan and Dietz (1965) found that plants on ponderosa pine forest sites in South Dakota were one or two weeks behind those on open meadows. Kentucky bluegrass and other graminoids growing in the forest were generally higher in protein, crude fibre, calcium and phosphorus than similar plants growing in the open (McEwan and Dietz 1965). However, the shaded forage was less palatable, possibly due to lower nitrogen-free extract percentages (McEwan and Dietz 1965) and sugar content (Watkins 1940).

Similarly, Wolters (1973) compared the chemical composition of herbage, mainly bluestem and panicum species, growing on clearcuts and under tree cover on longleaf/slash pine forest range in central Louisiana. The shaded plants were found to have higher protein and phosphorus content, and lower nitrogen-free extract values, than unshaded plants (Wolters 1983).

In eastern Oregon, Holechek et al. (1981) noted that cattle diets on a ponderosa pine/Douglas-fir forest range contained more crude protein in early and late summer than on neighbouring bluebunch wheatgrass range. They suggested that the difference could be attributed to the relatively high protein contents of forage shrubs such as ninebark, spiraea and snowberry, as well as to the delayed maturation of elk sedge and other herbs in the forest community.

In contrast to the results of these studies, Severson and Boldt (1977) detected no significant differences in the nutritional quality of plants growing on thinned and unthinned plots in a ponderosa pine forest in South Dakota when analyzed for digestible dry matter, protein, lignin, fiber, calcium and phosphorus ten years after thinning. Their sample sizes were quite small, however, and possibly not representative of the whole population. These results suggest that thinning may decrease the nutritional quality, but increase the palatability of forage in relation to unthinned stands.

Plant species composition and population dynamics are invariably altered by changes in the overstory since some species are more shade tolerant than others (Pase and Hurd 1958; Dealy 1975). In general, grasses tend to respond more favourably to thinning than forbs. For example, McConnell and Smith (1970) reported that pinegrass yields on a ponderosa pine site in Washington did not increase on unthinned or narrow spacing plots, but rose an average of 40% at wider spacings. Balsamroot, the principal forb, made its greatest gains on the unthinned plots (McConnell and Smith 1970). Similarly, Grelen et al. (1972) found that pinehill bluestem and other grasses were most productive on heavily thinned plots, while forbs such as southern bracken, swamp sunflower and poor-joe contributed more to total understory vegetation on densely timbered units in a Louisiana slash pine forest.

As with all generalizations, there are exceptions. For example, Pase and Hurd (1958) noted that shade tolerant species such as roughleaf ricegrass and Pennsylvania sedge increased their contribution to total herbaceous biomass with increasing tree basal area in a South Dakota ponderosa pine stand, while shade intolerant Kentucky bluegrass decreased in relative importance. On longleaf/slash pine plantations in Louisiana, Wolters (1982) found that pinehill bluestem and slender bluestem decreased under canopy cover, big bluestem and several panicum species increased, and fineleaf, paintbrush and broomsedge bluestems remained unaffected by canopy cover.

4.1.2.2 Prescribed Burning

The three main uses of prescribed burning in silvicultural treatments are (1) fuel reduction, (2) preparation of seedbeds, and (3) control of competing vegetation (Smith 1962). In certain forest types, particularly southern pine plantations, controlled burning is also employed to improve forage production and quality for grazing, thin dense stands of tree reproduction, and to control tree diseases, insects and rodent populations (Weaver 1947; Campbell 1954; Lay 1956; Smith 1962; Lewis and Harshbarger 1976; Grelen 1978).

In British Columbia, Wikeem and Strang (1983) reviewed the application and effects of prescribed burning on forest ranges in the PPBG and IDF zones. Their major conclusion was that insufficient information is presently available to achieve specific range management objectives through the use of prescribed fire (Wikeem and Strang 1983). Research requirements proposed by these authors include the collection of baseline data on: (1) the physical conditions of fuels, weather and topography for prediction of fire intensity, duration and behaviour; (2) the effects of fire on soils and plants; (3) post-burn interactions between fire and grazing on vegetation; and (4) the economics of range burning.

Studies to investigate the seasonal effects of fire on ponderosa pine and Douglas-fir forest range were recently initiated in the southern interior of British Columbia (Nyberg 1979; Smaill 1980; Strang and Johnson 1980). Unfortunately, only preliminary data have been reported to date and long-term results are not yet available. Nevertheless, the data at hand indicated that one year after burning the mean basal areas of the dominant understory grasses, bluebunch wheatgrass and rough fescue, were significantly reduced. However, actual numbers in each size class were essentially unaffected (Smaill 1980). Further, although understory production declined in response to burning, species composition remained relatively unchanged (Smaill 1980). There is a definite need for long-term research concerning the application of fire for range management purposes, particularly with regard to white spruce ranges northeast of Prince George (Nyberg 1979; Smaill 1980).

Considerable information is available on the historical role of fire in maintaining ponderosa pine/grasslands in the American Pacific Northwest, primarily Washington and Oregon (Biswell 1972; Weaver 1974). However, much of the published work on prescribed burning in this forest type has been based on observation and circumstantial evidence rather than rigorous experimental and statistical analysis (Weaver 1951; 1958; 1967). For example, Weaver (1951) observed that pinegrass and bluebunch wheatgrass on ponderosa pine forest range in Washington were apparently stimulated by fire, with heavy yields of these species usually occurring within three years after burning. In a later paper, Weaver (1958) noted that burning seemed to encourage grass production on these ranges through the thinning of dense ponderosa pine and Douglas-fir reproduction, the reduction of shrubs such as rose, snowberry and spiraea, and through possible fertilizing effects. In both cases, quantitative data supporting these observations were not given.

Campbell (1954) suggested that carefully controlled burning may be useful in managing grazed ponderosa pine forests to reduce wildfire hazard and thin dense stands of reproduction, thus improving forage yields. Ffolliott et al. (1977b) found that the general effect of prescribed burning in an Arizona ponderosa pine forest was to thin the overstory from below. Herbage following the fire exceeded pre-burning yields, but grazing values on the study site were negligible due to relatively low total production (Ffolliott et al. 1977b).

Fire may influence herbage composition as well as production. For instance, Ffolliott et al. (1977b) noted that species composition on burned ponderosa pine range changed from rather unpalatable mullein to a mixture of improved forage species, including bottlebrush squirreltail, mutton bluegrass and Fendler ceanothus.

In contrast, other studies have indicated that valuable forage plants may be harmed by burning. On unburned 4–5 year old Douglas-fir clearcuts in western Montana, it was reported that palatable grasses and grass-like plants made up 42% of the ground cover and less desirable forbs contributed 50% (Lewis 1965; Eddleman and McLean 1969). However, on comparable burned sites graminoids comprised only 4% of the vegetative cover and forbs increased to 91%. Similarly, graminoids made up 40% and 10% of the plant cover on unburned and burned 4–5 year old spruce/fir clearcuts in Montana, respectively, while corresponding forb cover on these sites was 30% and 77% (Lewis 1965).

Post-fire species composition is determined by the capacity of residual species to vegetatively reproduce, as well as by the rate of invasion of weeds or neighbouring native plants through dispersed seed. On the basis of plant root anatomy and underground reproductive structures, McLean (1969) determined the relative fire resistance of 30 understory species commonly occurring on forest range in the IDF zone of British Columbia. It was found that valuable forage species such as peavine, vetch, aster and pinegrass had fibrous roots and rhizomes which generally grew deep enough to escape mortality from burning, thus enabling these herbs to re-establish vegetatively. They were classified by McLean (1969) as moderately resistant to fire damage. However, his results also indicated that timber milkvetch and lupine were two undesirable plants which may increase on forest range after a fire because of their ability to regenerate from a tap root even when the entire plant crown had been destroyed (McLean 1969). Further, some species classified as susceptible to fire-damage, including hawkweed and arnica, were found to re-invade burned-over areas rapidly from wind-borne seed (McLean 1969).

The suppression of fire in ponderosa pine forests maintained by periodic wildfires may also alter the structure and composition of the plant community. In the Blue Mountains of eastern Oregon and southeastern Washington, fire prevention has resulted in a gradual replacement of ponderosa pine with grand fir and Douglas-fir (Hall 1976). The consequent increase in tree crown cover has drastically reduced ground vegetation and livestock carrying capacity. In addition, control of underburning has transformed the fire resistant ponderosa pine/pinegrass plant community to a fire susceptible fir/pinegrass-heartleaf arnica community (Hall 1976). The implication of these findings is that regular underburning is necessary to sustain open pine stands which are resistant to conflagration and permit ample forest grazing.

The pine forests of the southeastern United States have had a long history of prescribed burning in association with timber harvest or tree thinning to enhance grazing values (Grelen 1978). Grelen (1976) remarked that frequent removal of litter by burning generally encouraged the survival of enough grasses to ensure herbage recovery and desirable forage species composition after thinning or clearcutting in southern pine forests. However, he further pointed out from experimental work in Louisiana that without sufficiently wide initial spacings or thinnings by age 10, grazing would not be feasible in slash pine plantations by age 13, regardless of the burning schedule, because early burning did not prevent herbage yields from dropping sharply as the overstory developed.

In the longleaf pine forests of southeastern United States, the practice of annual burning was initiated as early as 1890 to keep the understory open and to stimulate native forage production (Grelen 1978). Although longleaf pine is adapted to fire, seedlings under a year old have been found to lack fire-resistance and annual burning thus proved to be extremely destructive to pine reproduction (Smith 1962; Croker 1975; Grelen 1978).

Grelen and Enghardt (1973) demonstrated that maturing longleaf pine forests in Louisiana could provide substantial quantities of forage for cattle, as well as good timber yields, if burned and thinned regularly at 3–5 year intervals depending on stand age. Herbage measurements over a 5 year period following experimental thinnings and prescribed burning at plantation age 30 showed that herbaceous biomass increased 2 to 3 times initial values within 4 years. Duvall and Whitaker (1964) reported that cattle use, distribution and weight gains were improved on longleaf pine ranges in Louisiana under a system of rotational burning. Herbage production was lower than unburned controls the first two years after burning, but was not significantly different in the third year. Increased forage utilization was also noted by Pearson (1974) following prescribed burning on longleaf pine range in Louisiana, although herbage yields were apparently not affected.

Higher use on burned range may possibly be due to enhanced nutritional quality of the forage. For example, Pearson et al. (1972) discovered that crude protein, phosphorous and *in vitro* digestibility were higher in forages from a burned ponderosa pine stand in northern Arizona than an adjacent unburned stand. Similar improvements in herbage protein and phosphorus were reported by Lay (1957) following prescribed burning of southern pine forests. However, this enhanced nutrient value has been found to be only temporary, with the effect usually disappearing within two growing seasons (Pearson et al. 1972).

Some improvement in forage composition may occur as a result of burning on southern pine ranges. A study of herb and shrub development after 20 years of prescribed burning on loblolly pine range in South Carolina indicated that good forage yields and diversity could be achieved by burning every 2 or 3 years during the winter (Lewis and Harshbarger 1976). Herbaceous species tended to increase with frequent burning while the cover of woody species decreased. Burning generally seemed to increase coverage by grasses, but only annual winter fires produced significantly greater gramineous cover than the unburned controls. Forbs were found to provide almost no coverage without burning (Lewis and Harshbarger 1976).

Hodgkins (1958) found a successional pattern from forbs to perennial grasses to perennial woody species following experimental burning in a loblolly/shortleaf pine forest in Alabama. He suggested that this trend revolved around the seeding and sprouting habits of the various species present on the site, and around the abilities of the plant forms to develop in size and to avoid smothering under organic litter (Hodgkins 1958).

4.1.3 Summary and Discussion

Late successional and climax forest ecosystems are characterized by the presence of a tree overstory and vertical stratification of the plant community. Canopy development in successional forests progressively reduces understory production. This negative relationship is logarithmic rather than linear, and it has been estimated that most losses in herbage yield on coniferous forest range in the Pacific Northwest have occurred by the time the canopy has reached 20–30% coverage.

Studies on ponderosa pine forests in western North America and on longleaf/slash pine forests in the southeast have indicated that herbage yields are influenced by a number of variables, including tree species, stand age, rate of tree growth, tree density, tree distribution, competing vegetation, precipitation, soils and physiographic features. However, factors associated with tree density, such as canopy cover and basal area, have generally been found to account for most of the variation in understory production in successional forest ecosystems.

Thinning is a silvicultural technique which removes surplus trees to concentrate the potential wood production of a stand on a limited number of selected trees. A secondary benefit is increased forage yields resulting from favourable changes in light quantity, quality and intensity, as well as in temperature and moisture conditions at the ground surface, which accompany opening of the tree canopy. However, it has been pointed out that this increased production cannot contribute significantly to the range resource without adequate treatment of the slash generated from the thinning process.

Apart from higher yields, there is some indication that thinning may affect the nutritional quality and palatability of forages by modifying the growing environment and altering plant physiology and phenology. Further, species composition may be changed since some plants are more shade-tolerant than others. In general, it has been observed that grasses tend to respond more positively to thinning than forbs.

Despite these generalizations, largely derived from research and observations in ponderosa and southern pine forests, many specific questions remain to be answered to enable scientific management of successional forest range in British Columbia. These include the following:

(1) Given that native forages differ from one biogeoclimatic zone to another, how do these species repond in terms of yield and quality to juvenile spacing and commercial thinning? What is the nature of the resulting plant community with respect to species composition, forage value and grazing capacity?

(2) How does herbage production differ under canopies of lodgepole pine, Douglas-fir, western larch, Engelmann spruce and white spruce?

(3) How do these herbage/timber relationships vary according to biogeoclimatic zone?

(4) Assuming silvicultural treatments are modified to accommodate range management objectives, how often would stands of lodgepole pine, Douglas-fir, Engelmann spruce or white spruce need to be thinned or pruned in order to maintain a desired level of forage production? What criteria should be used to determine this level of forage production? What effect would repeated thinnings or prunings have on tree growth and quality?

(5) At what point in a stand rotation does thinning cease to have an impact on tree and herbage production? Does this point differ depending on tree species?

(6) How does the increased development of herbs and shrubs after thinning affect the growth "release" and quality of remaining conifers?

Prescribed burning is the deliberate use of fire to achieve certain management objectives. These objectives include fuel reduction, seedbed preparation, control of competing vegetation, improvement of forage production and quality, thinning of dense stands of tree reproduction, and control of tree diseases, insects and rodent populations.

A considerable amount of literature has been published on prescribed burning in the ponderosa pine/ bunchgrass regions of the western United States. Most of this work has been of a qualitative rather than a quantitative nature. However, the information available suggests that burning acts to thin the tree overstory from below. Herbage yields tend to exceed pre-burning levels, and herbage quality is usually temporarily enhanced. Species composition normally changes, and the flora of the resultant plant community is primarily determined by the intensity of the fire, the fire-resistance and asexual reproductive capacity of the residual vegetation, and the rate of ingress of dispersed seed from adjacent, undamaged communities.

Similar results have been obtained in longleaf/slash and shortleaf/loblolly forests in southeastern United States. The use of fire in these forests has had a long and controversial history. However, it has been rather well documented that both silvicultural and range benefits may be achieved from prescribed burning. Often both thinning and burning have been used in conjunction to attain management objectives. For example, it has been pointed out that wide initial spacings or thinnings were required in slash pine stands because early burning on its own, beginning at stand age 5, did not affect survival and growth of young pines and did not prevent forage yields from dropping sharply as the overstory developed.

It is doubtful that much of the reseach from the southern pine forests is of direct relevance to the environmental conditions and forest communities found in British Columbia. Likewise, the information from the ponderosa pine forests lacks sufficient detail, precision and applicability to be of significant value in formulating strategies for multiple-resource management in B.C. A comprehensive review by Wikeem and Strang (1983) of prescribed burning on forest and grassland ranges in this province has identified the following as major areas for research:

(1) the collection of baseline data on the physical conditions of fuels, weather and topography for prediction of fire intensity, duration and behaviour;
(2) the effects of fire on soils and plants;
(3) post-burn interactions between fire and grazing on vegetation.

These research recommendations apply to all biogeoclimatic zones in which forest grazing is practised, including ESSF, ICH,IDF, MS, PPBG and SBS. Further, the fire responses of the dominant tree species of British Columbia's forest ranges should be examined, including conifers such as Douglas-fir, Engelmann spruce, white spruce and subalpine fir, and deciduous species such as aspen.

Since logged areas ultimately return to forest cover and tree dominance via secondary succession, considerable control can be exercised over timber and forage development on clearcuts if an integrated approach is adopted by foresters and range managers at the inception of a new stand rotation. This necessitates acceptance of the dual objectives of prolonging the grazing resource and encouraging selective tree growth through appropriate stand tending. Cooperative research is required to define and manipulate the ecological and economic constraints to forage production in late successional and climax forest ecosystems to achieve these two objectives.

4.2 Range Management in Stratified Forest Communities

In southern British Columbia, upper elevation forests have traditionally served as summer range while low altitude grasslands supplied spring and fall grazing (Tisdale et al. 1954; Reid 1979). As the forage matures over the grazing season, cattle are progressively pushed upward from bunchgrass ranges to ponderosa pine/ Douglas-fir, Douglas-fir/lodgepole pine and, to a lesser extent, Engelmann spruce/subalpine fir forest ranges (McLean 1979b; Reid 1979). Seasonal grazing in the northern part of the province is generally confined to low elevation forests of white spruce, lodgepole pine, subalpine fir and aspen (Watts 1983).

Forage yields and palatability on timbered ranges are usually depressed due to the presence of an overstory, with the notable exceptions of relatively open ponderosa pine and/or Douglas-fir stands (Morris 1947; Reid 1947; McLean 1979b). Further impacts on the plant community may be imposed by the grazing and browsing activities of livestock and wildlife (Krueger and Winward 1974). Conversely, the abundance and accessibility of forage influences animal distribution, grazing behaviour, forage utilization and hence beef production (Eddleman and McLean 1969; Miller and Krueger 1976; Clary et al. 1978; Roath and Krueger 1982). Range management seeks to balance the interrelationships between forage and livestock with the objective of simultaneously preserving the grazing value and realizing the livestock production potential of these forest range ecosystems.

4.2.1 Forage/Livestock Interactions

The productivity, distribution and abundance of forage plants depends not only on the influence of climate, soils and associated vegetation, but also on the intensity, season and frequency of grazing by domestic livestock and wild ungulates (Heady 1975). Forage utilization by cattle on late successional or climax forest range ecosystems is determined by a number of factors, including forage composition and production, forest density and canopy cover, distance to water or salt, steepness and length of slope, access, season of use and range condition (Hedrick et al. 1968; Miller and Krueger 1976; Clary et al. 1978). The impact of cattle on forage through selective grazing is manifested in reduced yields of preferred species and subsequent modification of understory structure and community composition (Krueger and Winward 1974; Pearson and Whitaker 1974).

4.2.1.1 Cattle Diets and Grazing Patterns

The relative forage values of native plants commonly found on forest ranges in southern British Columbia have been described by McLean et al. (1964). Among the more valuable of these herbs and shrubs are pinegrass, mountain brome, creamy peavine, aster, hawkweed, Saskatoon serviceberry, aspen, rose, snowberry and several species of willow. In addition, slender wheatgrass and blue wildrye may be locally important in forest openings (McLean et al. 1964).

Pinegrass may provide 40–50% or more of the ground cover and 50–60% of the forage yields on forest range in the IDF (Tisdale 1950; McLean 1967a). McLean (1967a) noted that this species was readily accepted by cattle during the early summer, but became rather unpalatable by mid-August. Forage quality analyses have shown that pinegrass declines in crude protein and dry matter digestibility, and increases in lignin, fibre and ash content over the growing season on native range in southern British Columbia (McLean et al. 1969).

Several of the forage species utilized by livestock in the southern biogeoclimatic zones are known to occur in subzones of the SBS and/or BWBS. These include pinegrass, aster, fireweed, creamy peavine, serviceberry, snowberry, aspen and willow (McLean 1979b), and when available may contribute significantly to cattle diets (McLean et al. 1964). No quantitative analyses of forage selection by cattle were found for timbered ranges in northcentral British Columbia, but a few studies were available for southern forest ranges.

In the IDF zone, McLean and Willms (1977) reported that proportional consumption of grasses, forbs, shrubs and trees on spring/fall range with an open Douglas-fir/lodgepole pine overstory averaged 93.5%, 1.4%, 1.3% and 4.0%, respectively. Bluebunch wheatgrass was the most important gramineous species, contributing up to 57.7% of the total feed intake by cattle during the spring grazing period.

On Douglas-fir summer range in the IDF, pinegrass was found to comprise roughtly 93% of the forage consumed (McLean and Willms 1977). Aster was the most preferred forb, with about 35% of the plants grazed. Browse utilization was determined to be 75%, 65%, 55%, 40%, 25% and 10% for snowberry, willow, serviceberry, rose, trembling aspen and alder, respectively (McLean and Willms 1977).

Similar results were noted by Willms et al. (1980) who studied forage selection by cattle in forest openings on a Douglas-fir/Engelmann spruce/aspen summer range in the IDF zone. In this study the graminoid component, primarily pinegrass, accounted for 41% of the total number of bites. The most preferred herbs and shrubs were white clover, fireweed and willow, which contributed 29%, 9% ad 6% of the total number of bites, respectively (Willms et al. 1980).

In contrast to the findings of McLean and Willms (1977), it was observed by Holechek et al. (1982) that the quantities of grass consumed by cattle on ponderosa pine/Douglas-fir range in northeast Oregon depended upon the period and the palatability of all forage available. Graminoid content, including Idaho fescue, elk sedge, bluebunch wheatgrass, pinegrass, western fescue and Kentucky bluegrass, varied from as little as 36% in late spring to as high as 83% in late summer. Idaho fescue and elk sedge comprised the bulk of the grass/sedge portion of the cattle diets in the latter half of the season because of their less advanced phenological development (Holechek et al. 1982).

The consumption of forbs, particularly heartleaf arnica, western yarrow and lupine, declined over the grazing season from an average of 29% of the diet in late spring to only 9% in fall (Holechek et al. 1982). Shrub utilization, mainly snowberry, spiraea and ninebark, depended on the availability of green herbage, and ranged from a low of 10% during a wet summer to a high of 47% in a dry summer. Holechek et al. (1982) concluded from their study that cattle on forested ranges were opportunistic grazers and would readily shift their diets over the grazing season.

The production and distribution of forage plants on a forest range unit may be largely determined by the nature and extent of the tree overstory, creating an indirect relationship between tree density/crown cover and animal dispersion/forage utilization. In some situations, this correlation may be more important than such factors as topography or distance to water in controlling animal grazing patterns.

For example, Clary et al. (1978) employed the multivariate statistical technique of multiple regression to identify the major factors influencing forage consumption by cattle in Arizona ponderosa pine forests. The dependent variables were (1) amount of forage consumed and (2) utilization of perennial grasses. The eight independent variables were (1) perennial grass production, (2) average preference rating for grasses, (3) ponderosa pine density as measured by basal area, (4) percent forest crown over, (5) percent slope, (6) distance from water, (7) elevation, and (8) soils. It was found that perennial grass production and pine basal area accounted for 67% and 61%, respectively, of the variation in weight of forage consumed. On this particular study site topography was gentle, distance to water was not far and average forage preferences did not vary greatly (Clary et al. 1978).

Similarly, Miller and Krueger (1976) used multiple regression analysis to explain the variability in weight of forage harvested by cattle on bunchgrass, clearcut and mixed conifer summer ranges in northeastern Oregon. In this study, the combined effect of distances to water and salt accounted for 79% of the variability. With the addition of soil depth and canopy cover into the analysis, 99% of the variability in forage consumed was explained. The latter two environmental factors were strongly correlated with forage yields in each community (Miller and Krueger 1976).

Kranz and Linder (1973) reported that cattle preferred aspen communities over mixed aspen/ponderosa pine or pure ponderosa pine stands in the Black Hills of South Dakota. Basal areas averaged 21, 31 and 41 m^2/ha for aspen, aspen/pine and pine forests respectively. Grass production on these sites averages 203, 146 and 64 kg/ha, respectively. Thus, the authors concluded that cattle preference for these communities was directly related to understory grass production, and hence indirectly related to forest density (Kranz and Linder 1973).

In Arizona, cattle were found to prefer openings in ponderosa pine (Reynolds 1966a) and spruce/fir (Reynolds (1966c) forests more than the surrounding treed areas. Cattle distribution appeared to be associated with perennial grass production on these forest ranges (Reynolds 1966a).

It has been reported that moderate to heavy forage utilization by cattle was difficult to obtain under dense overstory canopies in the mixed grand fir/Douglas-fir/larch forests of northeast Oregon (Young et al. 1967a; Hedrick et al. 1968). However, when the herd was separated on the basis of age, it was observed that younger animals, including yearling heifers, first-calf and second-calf cows, voluntarily used densely timbered areas where older cows would not graze (Young et al. 1967a; Hedrick et al. 1968). No explanation for this difference in behaviour between age classes was given.

Roath and Krueger (1982) analyzed cattle grazing behaviour on ponderosa pine/Douglas-fir range in the southern Blue Mountains of Oregon. Ten vegetation types were represented on the grazing unit, of which three accounted for 96% of the total forage utilized. The riparian zone, dominated by Kentucky bluegrass, contributed 21% of the total herbaceous biomass produced on the unit and 2% of the total area, but provided 81% of the forage consumed. The ponderosa pine upland type accounted for 39% of the area and 12% of the forage consumed, while the Douglas-fir/elk sedge type comprised 38% of the land area and 3% of the forage utilized. The authors found that areas with little use were characterized primarily by steep slopes, closed tree canopy, north and west aspects and sparse understory vegetation. They also noted that where these factors did not constrain cattle distribution, distance from water ultimately controlled the limit of vegetation utilization (Roath and Krueger 1982).

The herd studied by Roath and Krueger (1982) was observed to segregate into three discrete grazing groups with distinct "home ranges". Although the factors determining animal associations within each group were not identified, the groups appeared to be socially-structured, hierarchical assemblages which occupied the same home range year after year. Further, Roath and Krueger (1982) reported that these groups seemed to be semi-independent of one another, suggesting that cattle numbers could be manipulated in one group without substantially altering other groups. Thus, it was pointed out that a knowledge of herd structure and grazing groups could assist in managing livestock effectively for more efficient utilization of forage resources (Roath and Krueger 1982).

4.2.1.2 Impact of Grazing on the Plant Community

Hedrick (1958) stressed that the physiological reaction of plants to grazing should form the basis for developing sound grazing management practices and proper utilization of forage plants. This view was shared by Kinsinger (1979) who argued that the establishment of a sustained livestock industry dependent upon natural vegetation involved much more than simply a survey to find out where the forage was and how much was there. It also included ecological, phenological and physiological studies of individual species, as well as a comprehensive knowledge of plant community dynamics in response to grazing and other ecosystem perturbations (Klemmedson et al. 1978; Kinsinger 1979).

Selective grazing by livestock or wildlife affects the yields and distribution of preferred forage species, with accompanying changes in plant community composition and future grazing potential. Such changes have not been documented for late successional forest ranges in British Columbia. However, limited research on forested rangelands elsewhere has examined the impact of cattle grazing in some detail.

For example, the effects on herbage production of two grazing systems and three stocking levels have been investigated over an 11-year period on ponderosa pine/Douglas-fir range in the American Pacific Northwest (Skovlin and Harris 1970; Skovlin et al. 1976). It was found that herbage loss in the graminoid group was directly proportional to the rate of stocking. Highly preferred elk sedge showed average losses of 7, 16 and 23 kg/ha for light, moderate and heavy stocking rates, respectively, by the end of the study (Skovlin et al. 1976). However, it was noted that losses were significantly less for elk sedge under deferred-rotation than under season-long grazing.

Although figures were not presented, Skovlin et al. (1976) reported that pinegrass production declined even more than elk sedge despite lower utilization. In contrast to the early maturing elk sedge, pinegrass losses were not reduced by deferred rotation grazing. Because of its later maturity, pinegrass apparently was not protected during its critical maturation stage by deferment of grazing to midseason (Skovlin et al. 1976).

Interestingly, net forage production did not change although total herbage production decreased over the 11-year study period (Skovlin et al. 1976). Grazing capacity was reduced on average by about 10 AUMs under deferred-rotation grazing, and by approximately 14 AUMs under the season-long system (Skovlin et al. 1976). Losses were greatest under heavy stocking rates, but were not significantly different between grazing systems.

Krueger and Winward (1974) found that the understory structure of a Douglas-fir/ponderosa pine/Kentucky bluegrass community in northeastern Oregon was significantly changed after 14 years of grazing by cattle and big game. The authors noted that grazing by big game alone resulted in minor modification of the herbaceous component, primarily because populations in the study area were not large enough to exert a significant impact on the community. Thus, much of the observed grazing effect was apparently due to cattle.

The duration of use varied from year to year on the study site, but in all years utilization was determined to be heavy (Krueger and Winward 1974). In general, it was observed that graminoids tended to decline and forbs to increase under heavy use. For example, the frequencies of elk sedge and junegrass were significantly greater in areas protected from cattle grazing, while frequencies of western yarrow, fleabane, dandelion and sheep sorrel were significantly less (Krueger and Winward 1974).

It has been reported that light, moderate and heavy grazing did not affect total herbage production on rotationally burned slash pine ranges in central Louisiana, but apparently altered the botanical composition of the understory (Pearson 1974; Pearson and Whitaker 1974; Clary 1979). Percent composition of pinehill bluestem, the most important cattle forage species in the area, was reduced by all grazing intensities. Conversely, undesirable carpetgrass was observed to increase with grazing pressure (Pearson 1974; Pearson and Whitaker 1974; Clary 1979).

The true impact of grazing on these particular southern pine ranges was partially confounded by the tree overstory and burning. It was consistently pointed out that canopy cover reduced forage yields and favoured the growth of forbs over grasses as the slash pine stands matured (Pearson 1974; Pearson and Whitaker 1974; Clary 1979). Pearson (1974) reported that prescribed burning apparently did not affect herbage yields in his study, but did increase forage utilization. Nevertheless, it has been shown that fire can change understory structure and composition independently of grazing or overstory effects, as demonstrated by Hodgkins (1958) for shortleaf/loblolly pine stands in Alabama and Ffolliott et al. (1977b) for ponderosa pine forests in Arizona.

The fact that grazing and tree canopy cover simultaneously effect the botanical composition of understory vegetation in forested plant communities leads to difficulties in interpreting causes of forest range trend and in evaluating forest range condition. Hall (1978) pointed out that measurement of tree crown cover was required in sampling for condition and trend as a means of separating the effects of livestock management from the effects of trees. Using tree cover categories as reference points, consistent interpretation of range condition and trend caused by livestock grazing was possible within each category (Hall 1978). However, application of this concept to British Columbia forest ranges has not yet been attempted (Pitt 1983).

4.2.2 Cattle Production

Since forage yields are generally lower in late successional and climax forest ecosystems than in early seral communities, cattle stocking rates on the former must be reduced accordingly. A comparison of stocking rates and average daily gains for clearcut and forested ranges in the Pacific Northwest is summarized in Table 31. These data suggest that stocking densities on forested ranges may be less than half the levels found on more productive clearcut pastures.

As pointed out in Section 3.3.1.2, average daily gains are a function of several variables including class of animal, abundance and quality of available forage, and the portion of the grazing season over which the gains are calculated. In southern British Columbia, McLean (1967a; 1972) reported that yearling steers grazed on lodgepole pine/pinegrass ranges from mid-June/early July to late September/early October gained an average of 0.79 kg/day. No comparable work has been done in British Columbia on forest range dominated by other conifers, including Douglas-fir, spruce or true firs.

Hedrick et al. (1969) found that yearling steers stocked on a mixed conifer/pinegrass range in northeast Oregon from mid-May to late August had average gains of only 0.48 kg/day. In discussing the results of their research in relation to McLean's (1967a) work, Hedrick et al. (1969) attributed the difference in gains to the lighter animals used in the British Columbia study.

TABLE 31. Stocking rates and average daily gains for two clear cut and two forested ranges in the Pacific Northwest

Range Type (Tree Spp)	Location	Stocking (ha/AUM)	Average Daily Gains (kg)	Class of Animal	Source
Clearcut (Pl, Se)	B.C.	0.73	0.64	calves	McLean & Clark (1980)
			0.13	cows	
Forest (Pl)	B.C.	1.94	0.79	yearling steers	McLean (1967a; 1972)
Clearcut (Py, Fd, Lo, Pw)	Oregon	0.66*	0.74	yearling steers	Vavra et al. (1980)
Forest (Bg, Fd, Lo, Py)	Oregon	1.21	0.48	yearling steers	Hedrick et al. (1969)

* Stocking rate calculated from data given; yearling steer units multiplied by 0.6 to obtain animal units (AU) as in McLean (1967a).

Increased stocking density may lead to higher weight gains per unit area, but lower gains per individual animal. Skovlin et al. (1976) investigated the effects of three stocking levels on cow and calf weight gains, per head and per hectare, on ponderosa pine/bunchgrass range in northeastern Oregon (Table 32). Their results indicated that average cow gain per hectare remained unchanged at light and moderate stocking rates, but was significantly less with heavy stocking. In contrast, calf gain per hectare increased considerably with higher stocking levels. Gains per head declined substantially for both classes of animal as stocking density was increased.

TABLE 32. Effect of stocking rate on cow and calf gains, per head and per hectare, on ponderosa pine range in Oregon (Skovlin et al. 1976)

Stocking Rate ha/AUM	Cows		Calves	
	kg/head/yr	kg/ha/yr	kg/head/yr	kg/ha/yr
4.0	16.8	1.12	88.0	5.71
1.2	13.2	1.12	81.7	6.95
0.8	−1.8	−0.11	76.2	8.96

The tree overstory on forest range may have a marked effect on beef production through its influence on forage production and quality, as well as on animal behaviour and nutrition. For example, Clary et al. (1975) found that beef gain potential for yearling cattle on ponderosa pine range in Arizona was 36 kg/ha/yr on a clearcut, but was 33% less on a site where tree basal area was 4.5 m^2/ha. Potential gains had decreased by approximately 70% or 25 kg/ha/yr when pine basal area reached 14 m^2/ha. Clary et al. (1975) attributed the reduced gains to lower forage production and cattle carrying capacity at higher tree basal areas.

In another study, cattle weight gains were compared between bluebunch wheatgrass and ponderosa pine/Douglas-fir ranges in eastern Oregon (Holechek et al. 1981; Vavra 1983). Although productivity estimates fluctuated from season to season and from year to year, average daily gains were generally found to be significantly highter on the forest range in early and late summer. Forage quality analyses indicated that improved gains may be due to the higher crude protein in the forest diet during this period (Holechek et al. 1981). Higher protein contents were attributed to the later phenological development of herbage and the abundance of nutrient-rich shrubs under the forest canopy (Holechek et al. 1981).

Increased weight gains on forested ranges may also be associated with the influence of shade. Hess et al. (1962) found that shaded steers gained 18 kg more than unshaded control animals when summer grazed on irrigated pasture in southern Alberta. On sagebrush/grassland range in northwestern Oklahoma, McIlvain and Shoop (1971) reported that average steer gains over the summer were 147 kg for a treatment group provided with artificial shade, and 135 kg for an unshaded control group. These authors suggested that shading relieved physiological stresses due to high temperatures, thus reducing weight loss (McIlvain and Shoop 1971). However, the significance of shade in relation to animal gains on forest range has not been studied.

4.2.3 Summary and Discussion

Range management in late successional and climax forest ecosystems is concerned with the efficient use of timbered range to produce livestock and perpetuate the forage resource. Forage utilization by cattle on such sites is determined by a number of factors, including plant species composition and production, forest density and canopy cover, distance to water and salt, topography, access, season of use and range condition. The relative importance of each factor is dictated by the specific environmental characteristics of a given site. However, studies on ponderosa pine and mixed grand fir/Douglas-fir ranges have shown that forage plant production and tree density frequently exerted the most influence on grazing patterns and forage consumption.

It has been generally reported that cattle feed primarily on grass and grasslike species, but research in the Pacific Northwest has suggested that cattle may be opportunistic grazers in forest communities and may readily shift their diets according to the season and the palatability of all forage available. In British Columbia, cattle diets have been investigated on forest range in the IDF, but quantitative studies of forage selection in such biogeoclimatic zones as the BWBS, ESSF, ICH, MS and SBS are lacking. Thus, baseline data is required assessing the range potential of these zones. Information needs include:

(1) assessment of seasonal and annual forage production;
(2) determination of the nutritional value of important native forage species throughout the seasonal grazing period; and
(3) study of domestic livestock diets throughout the seasonal grazing period.

Range managers require a comprehensive knowledge of vegetation changes due to cattle grazing in order to manage the plant community on a sustained yield basis through appropriate stock manipulation. Grazing may alter the species composition and productivity of forest range communities. However, the impact of grazing is often confounded by overstory effects, leading to problems in the evaluation of forest range condition and trend.

A possible method for separating the effects of livestock from those of canopy cover or tree density has been presented in the literature, based on studies in the mixed conifer forests of Oregon. The technique involves the use of tree cover categories as reference points to derive consistent interpretation of condition and trend caused by grazing within each category. However, the concept has not yet been applied to forested rangelands in British Columbia.

For effective management of livestock on the forest ranges of this province, research is necessary to determine range condition guidelines at the ecosystem association level of the B.C. Ministry of Forests ecological classification. These guidelines should include the identification of increaser, decreaser and invader species for each forest range site, as well as criteria for appraising range readiness for major forage species on these sites. Further, the guidelines should consider forage yield, canopy cover and their resultant effect on land use objectives.

Cattle production is generally lower on late successional or climax forest ranges than seeded clearcuts. Although weight gains per individual animal may be comparable, stocking rates are lower on the former because of diminished forage production. Thus, overall beef gains per hectare are correspondingly reduced under forest cover. Further, it has been shown from research in ponderosa pine forests that potential beef gains decrease curvilinearly with increasing tree basal area. Although the shape of this curve may differ according to tree species, the inverse relationship is expected to remain consistent for all forest range types.

Despite the negative impact of the tree overstory on forage yields, the delayed maturation of forest herbs results in somewhat higher forage quality on forested range compared to grassland range late in the grazing season. During this period, the higher forage quality may be translated into higher weight gains. As well, increased weight gains over the summer months may be associated with the influence of shade. However, additional research is needed to clarify these relationships and to assess the significance of enhanced forage quality and shade in compensating for low forage quantity in terms of livestock production.

A major problem in the grazing management of forested rangelands is the difficulty encountered in obtaining a uniform distribution of cattle over a range unit. Overutilization of forage generally occurs on easily accessible areas such as forest openings, whereas forage under canopy cover may be largely ignored. Common management practices to correct this disparity in use include fencing, water developments, trail clearing, salting and riding. In addition, a knowledge of herd structure, behaviour and plant community preferences may assist in effectively managing forest range resources.

In British Columbia, the relationships between livestock distribution and habitat use on different forest range sites need to be clarified. Further, behavioural studies on social interactions within and between grazing groups may be useful in manipulating livestock numbers and distribution to achieve more efficient and homogeneous utilization of forage.

5 ECONOMIC ASPECTS OF TREE/FORAGE/LIVESTOCK INTERACTIONS

It is well recognized that forests yield a wide variety of products, including timber, forage, recreation and wildlife. Deciding among alternatives or determining optimal mixes of forest products usually involves economic tradeoff analysis of the costs and benefits associated with each use.

Brown (1976) described a decision-making procedure to follow in performing such analyses:

(1) formulate forest management alternatives;
(2) predict corresponding resource yields using available ecological data and response or simulation models;
(3) express the costs and benefits of various outputs in dollar terms, where possible, and determine the effects of the alternatives on the local economy;
(4) compare the alternatives in relation to biophysical, dollar, local income and employment, and non-quantifiable effects.

Thus, the amount of each resource output in integrated management necessarily depends on several considerations, including physical and biological feasibility and consequences, economic efficiency, economic equity, social or cultural acceptibility, and operational or administrative practicality (Brown and Carder 1977; Carder 1977). Further, maximum yields of individual products will generally not be achieved through combined use, although an overall increase in total value may occur (Lewis 1973).

In most parts of interior British Columbia, forestry and grazing are major uses of Crown forestland (Moss 1977). Nevertheless, published studies addressing the economic aspects of tree/forage/livestock interactions are lacking.

Moss (1977) reported that he was unable to find good information on the integrated costs of multiple-use forest management in this province. He pointed out that many management activities, such as broadcast burning after logging, provide benefits to both range and timber resource users. Thus, cost sharing of these operations was indicated (Moss 1977). Similarily, one can argue for the sharing of thinning costs.

He further suggested that if large scale grass seeding of cutbacks prevented natural regeneration of trees, it may lead to long-term and widespread effects on the timber producing capacity of the forestland base (Moss 1977). However, he did not present either biological or economic data to support this statement.

Outside of British Columbia, slightly more information is available. Sassaman (1972) described a method to calculate the economic rate of return from forage seeding on forest ranges in the Pacific Northwest given the average seeding cost and forage value. However, he assumed that periodic thinnings to a basal area of 20 m^2/ha would maintain domestic forage yields throughout the rotation and that the cost of seeding forage in the first year of the stand rotation was the only cost associated with the seeding decision. Further, he disregarded the importance of non-economic benefits derived from seeding, such as erosion control and wildlife habitat improvement.

One means of integrating long-term timber and range objectives is to manage forest stands on long rotations with low tree stocking densities to maintain forage. However, with the use of data from a slash pine forest in southeastern United States and a simulation model to compute tree and grass production, McMinn (1980) found that wood fibre production could be increased without sacrificing grass yields by increasing tree stocking and reducing rotation length. Further, it was shown that neither wood fibre nor grass yield was increased by setting the rotation age above the point at which production of wood fibre peaked (McMinn 1980).

On ponderosa pine range in Arizona, Clary et al. (1975) examined the relationship between livestock and timber production to determine which combination of the two forest products yielded the greatest dollar returns. The range measure used in his analysis was livestock carrying capacity, calculated as yearling-days of grazing/hectare/year. Wood production was measured as commercial volume of timber produced/hectare/year. At the time of the study, using 1972 dollars, the maximum economic output occurred at a basal area of about 12 m^2/ha with 250 bd ft/ha/yr of timber and 26 yearling-days/ha/yr (Clary et al. 1975).

Similarly, the economic aspects of forage utilization on forest range have been determined. For example, Pearson (1973) derived a profit formula based on forage production, digestibility and utilization, animal weight and daily gain, costs per animal day, and beef prices to calculate the percentage utilization that produced maximum livestock returns on ponderosa pine summer range in northern Arizona. He found that forest range with an Arizona fescue/mountain muhly understory producing 561 kg/ha of forage and grazed by 227 kg yearling cattle was used most economically at 30% utilization. Likewise, range producing 1123 kg of forage per hectare was grazed most economically at 38% utilization (Pearson 1973). However, a grazing intensity of 57% utilization was found to yield highest returns per hectare and not damage tree regeneration seriously on a slash pine plantation producing 2245 kg/ha of forage annually in central Louisiana (Pearson and Whitaker 1973).

Despite the general relevance of these American studies, a number of specific economic questions remain to be answered with regard to integrated use of British Columbia forest ranges. These include the following:

(1) What are the economic costs to the forest manager in terms of reduced height and diameter growth of tree seedlings due to grass competition and/or cattle damage?
(2) What are the economic benefits to the forest manager in terms of (i) reduced competition between tree seedlings and seeded grasses through grazing, and (ii) thinning of dense natural regeneration by grass competition or trampling?
(3) What are the economic costs to the grazier in terms of lost forage and livestock production potential if accessible clearcuts are not seeded and grazed?
(4) What are the economic returns to the grazier from stocking livestock on seeded clearcuts?
(5) What are the economic benefits and costs of tree thinning for timber and forage production?
(6) What are the economic benefits and costs of using fire to improve conifer stands for tree and forage production?
(7) Does multiple-use management for both timber and forage provide greater economic returns over the long-term than single-use management of Crown forestland in B.C.?
(8) What are the costs and benefits to the local economies of interior communities from multiple-resource management of provincial forests?

Clearly, the conflicts between forest and range users can be expected to continue until these economic questions have been addressed by researchers.

6 CONCLUSIONS

The ecological aspects of tree/forage/livestock interactions on forest range in British Columbia are complex. As pointed out by Costello (1957) in a discussion concerning the application of ecology to range management, "nature is not simple . . . and the proper interpretation of her processes is not simple". This complexity has led to serious conflicts between timber and beef producers in attempts to integrate the two uses of Crown forestland through multiple-resource management.

Forest range may be divided into two fundamental classes based on the absence or presence of an overstory:

(1) herb and shrub dominated forest range in early successional forest ecosystems;
(2) tree dominated forest range in late successional and climax forest ecosystems.

The former, which includes clearcuts and newly burned wildfire sites, holds considerable potential for range expansion in many parts of British Columbia. However, there remains some question as to the compatibility of tree regeneration and seeded forage grasses. Further, cattle have been shown to trample and occasionally browse young conifer seedlings. Most of the available literature on this subject suggests that the impacts of domestic forages and livestock on reforestation are generally minor and, given adequate management and coordination, the two uses of forestland are believed to be compatible. Nevertheless, there is considerable scope for additional research and, if a truly scientific approach to forest range management is to be achieved in British Columbia, further experimental study of the biological and economic aspects of tree/forage/livestock interactions on clearcuts is essential.

Climax forest range permanently suited to livestock grazing is generally found on sites with inherently low timber producing potential. The tree canopy is relatively open, and further development of the overstory is usually unlikely due to climatic or edaphic constraints. Thus, it is expected that such climax forest ranges may be maintained through proper grazing management given reliable range condition guidelines. These guidelines should be based on comprehensive range inventories and autecological studies of native forage species.

Late successional forests recovering from logging disturbance or wildfire on highly productive forestland will progressively diminish in significance as summer range with increasing canopy development. Silvicultural practices such as intermediate cutting and prescribed burning may extend grazing values for an undetermined period. However, close cooperation is required between timber and range managers for successful management of both resources. Again, additional research is necessary to clarify the ecological and economic relationships between stand tending and forage production on these sites to provide a scientific basis for sound management decisions.

Many of the research recommendations proposed in this study have been previously identified in reviews by Hanson (1974), Clark (1975) and Ross (1977) on forest grazing in British Columbia. The fact that these recommendations must be reiterated almost a decade later may partially account for the continuing debate between timber and range users of Crown forestland. It is imperative that the basic ecological research needed on the primary resources of this province receive serious attention if the goal of integrated multiple-use is to be realized.

7 LITERATURE CITED

Adams, S. N. 1975. Sheep and cattle grazing in forests: a review. J. Appl. Ecol 12:143–152.

Ahlgren, I. F., and C. E. Ahlgren. 1960. Ecological effects of forest fires. Bot. Rev. 26:483–533.

Anderson, C. H. and C. R. Elliott. 1957. Studies on the establishment of cultivated grasses and legumes on burned-over land in northern Canada. Can. J. Plant Sci. 37:97–101.

Anderson, E. W., and L. E. Brooks. 1975. Reducing erosion hazard on a burned forest in Oregon by seeding. J. Range Manage. 28(5):394–398.

Arlidge, J. W. C. 1967. The durability of scarified seedbeds for spruce regeneration. B.C. For. Serv. Res. Note No. 42, 20 p.

Armit, D. 1966. Silvics and silviculture of lodgepole pine in the north central interior of British Columbia. B.C. For. Serv. Res. Note No. 40, 50 p.

Arnold, J. F. 1950. Changes in ponderosa pine-bunchgrass ranges in northern Arizona resulting from pine regeneration and grazing. J. For. 48:118–126.

Baker, F. S. 1949. A revised tolerance table. J. For. 47:179–181.

Baer, N., F. Ronco, and C. W. Barney. 1977. Effects of watering, shading and size of stock on survival of planted lodgepole pine. U.S.D.A. For. Serv. Res. Note RM-347, 4 p.

Baron, F. J. 1962. Effects on different grasses on ponderosa pine seedling establishment. U.S.D.A. For. Serv. Res. Note PSW-199, 8 p.

Basile, J. V., and C. E. Jensen. 1971. Grazing potential on lodgepole pine clearcuts in Montana. U.S.D.A. For. Serv. Res. Paper INT-98, 11 p.

Beaton, J. D. 1959. The influence on burning of the soil in the timber range area of Lac le Jeune, British Columbia. I. Physical properties II. Chemical properties. Can. J. Soil Sci. 39(1):1–11.

Berglund, E. R. 1976. Seeding to control erosion along forest roads. Ore. State Univ., Corvallis. Exten. Circ. No. 885, 19 p.

Bethlahmy, N. 1960. Fertilizer helps establish grass seedlings on abandoned logging roads. J. For. 58:965–966.

Beveridge, A. E. and B. K. Klomp. 1973. Tolerance of *Pinus radiata* to grass competition. N.Z. J. For. 18:148–151.

Beveridge, A. E., B. K. Klomp, and R. L. Knowles. 1973. Grazing in young plantations of *Pinus radiata* pine established after clearing logged and reverted indigenous forest. N.Z. J. For. 18:152–156.

Biswell, H. H. 1972. Fire ecology in ponderosa pine-grassland. Proc. Annual Tall Timbers Fire Ecol. Conf. 12:69–96.

Blackmore, D. G., and W. M. Corns. 1979. Lodgepole pine and white spruce establishment after glyphosate and fertilizer treatments of grassy cutover forest land. For. Chron. 55(3):102–105.

B.C. Min. For. 1982. Annual Report, 1981–82. B.C. Min. For., Victoria. 55 p.

B.C. Min. For. 1981. Annual Report, 1980. B.C. Min. For., Victoria. 59 p.

B.C. Min. For. 1980. Forest and Range Resource Analysis Technical Report, Vols. 1 and 2. Info. Serv. Br., B.C. Min. For., Victoria. 802 p.

Brown, R. T. 1967. Influence of naturally occurring compounds on germination and growth of jack pine. Ecol. 48:542–546.

Brown, T. C. 1967. Alternatives analysis for multiple use management: A case study. U.S.D.A. For. Serv. Res. Paper RM-176, 16 p.

Brown, T. C., and D. R. Carder. 1977. Sustained yield of what? J. For. 75(11):722–723.

Campbell, R. S. 1954. Fire in relation to forest grazing. Unasylva 8(4):154–158.

Carder, D. R. 1977. Multi-resource management research in the southwest — the Beaver Creek program. J. For. 75(9):582–584.

Carmean, W. H. 1971. Large, well balanced stock and control of grass competition needed for red pine plantings on sandy soils. Tree Planters' Notes 22:8–10.

Carr, W. W. 1980. A handbook for forest roadside erosion control in British Columbia. B.C. Min. For. Land Manage. Rep. No. 4, 33 p.

Cassady, J. T., W. Hopkins, and L. B. Whitaker. 1955. Cattle damage to pine seedlings. U.S.D.A. For. Serv., S. For. Expt. Sta., Occas. Paper 141, 14 p.

Central Interior Forage Extension Committee. 1981. Management and improvement of organic wetlands in the interior of British Columbia. B.C. Min. Agric. Pub. No. 81-3, 12. p.

Chernoff, J. F. 1976. Scarification and forage crop seeding as an attempt to improve seed-bed conditions in the interior Douglas-fir zone of the Cariboo Forest District. B.S.F. Thesis, Univ. Brit. Columbia, Vancouver. 36 p.

Christ, J. H. 1934. Reseeding burned-over lands in northern Idaho. Univ. Idaho, Moscow. Agric. Expt. Sta. Bull. No. 201, 28 p.

Clark, M. B. 1975. Grass-conifer compatibility: A problem analysis. Unpub. Rep., B.C. For. Serv. Res. Sect., Kamloops, B.C. 22 p.

Clark, M. B., and A. McLean. 1979. Growth of lodgepole pine seedlings in competition with grass. B.C. For. Serv. Res. Note 86, 13 p.

Clark, M. B., and A. McLean. 1978. Compatibility of grass seeding and coniferous regeneration on clearcuts in the south central interior of British Columbia. B.C. For. Serv. Res. Note 83, 25 p.

Clark, M. B., and A. McLean. 1975. Growth of lodgepole pine seedlings in competition with different densities of grass. B.C. For. Serv. Res. Note 70, 8 p.

Clark, M. B., and A. McLean. 1974. Compatibility of grass seeding and coniferous regeneration on clearcuts in the south central interior of British Columbia. B.C. For. Serv. Res. Note 63, 10 p.

Clary, W. P. 1979. Grazing and overstory effects on rotationally burned slash pine plantation ranges. J. Range Manage. 32(4):264–266.

Clary, W. P., P. F. Ffolliott, and F. R. Larson. 1978. Factors affecting forage consumption by cattle in Arizona ponderosa pine forests. J. Range Manage. 31(1):9–10.

Clary, W. P., W. H. Kruse, and F. R. Larson. 1975. Cattle grazing and wood production with different basal areas of ponderosa pine forests. J. Range Manage. 28(6):434–437.

Costello, D. F. 1957. Application of ecology to range management. Ecol. 38:49–53.

Croker, T. C. 1975. Longleaf pine seedlings survive fire in clearcut strips. U.S.D.A. For. Serv. Res. Note SO-188, 3 p.

Crouch, G. L. 1979. Atrazine improves survival and growth of ponderosa pine threatened by vegetative competition and pocket gophers. For. Sci. 25(1):99–111.

Crouch, G. L. 1969. Deer and reforestation in the Pacific Northwest. *In:* Wildlife and Reforestation in the Pacific Northwest, H. C. Black (ed.), School For., Ore. State Univ., Corvallis. p. 63–66.

Crouch, G. L., and M. A. Radwan. 1981. Effects of nitrogen and phosphorus fertilizers on deer browsing and growth of young Douglas-fir. U.S.D.A. For. Serv. Res. Note PNW-368, 15 p.

Currie, P. O., C. B. Edminster, and F. W. Knott. 1978. Effects of cattle grazing on ponderosa pine regeneration in central Colorado. U.S.D.A. For. Serv. Res. Paper RM-201, 7 p.

Daubenmire, R. 1978. Plant Geography: With Special Reference to North America. Academic Press, New York. 338 p.

Daubenmire, R. 1968a. Ecology of fire in grasslands. Adv. Ecol. Res. 5:209–266.

Daubenmire, R. 1968b. Plant Communities: A Textbook of Plant Synecology. Harper and Row, New York.

Daubenmire, R. 1952. Forest vegetation of northern Idaho and adjacent Washington and its bearing on concepts of vegetation classification. Ecol. Monogr. 22:301–330.

Daubenmire, R., and J. B. Daubenmire. 1968. Forest vegetation of eastern Washington and northern Idaho. Wash. State Univ., Pullman. Agric. Expt. Sta. Tech. Bull. 60, 104 p.

Davis, P. R. 1977. Cervid response of forest fire and clearcutting in southeastern Wyoming. J. Wildl. Manage. 41(4):785–788.

Dealy, J. E. 1975. Management of lodgepole pine ecosystems for range and wildlife. *In:* Management of Lodgepole Pine Ecosystems, D. M. Baumgartner (ed.), Coop. Exten. Serv., Wash. State Univ., Pullman. p. 556–568.

Decker, A. M., T. H. Taylor, and C. J. Willard. 1973. Establishment of new seedings. *In:* Forages, the Science of Grassland Agriculture, 3rd Edition, M. E. Heath, D. S. Metcalfe, R. F. Barnes (ed.), Iowa State Univ. Press, Ames. p. 384–395.

Denham, A. C. 1959. Compatibility of grass and trees on eastside Oregon and Washington forests. Proc. Soc. Amer. For. 1959:164–166.

Dobbs, R. C. 1972. Regeneration of white and Engelmann spruce: A literature review with special reference to the British Columbia interior. Pacific For. Res. Centre, Can. For. Serv., Victoria, B.C. Info. Rep. BC-X-69, 77 p.

Dodd, C. J. H., A. McLean, and V. C. Brink. 1972. Grazing values as related to tree-crown cover. Can. J. For. Res. 2(3):185–189.

Duffy, P. D. 1974. Planting grass and pine for erosion control. Tree Planters' Notes 25 (1):10–13.

Duvall, V. L., and L. B. Whitaker. 1964. Rotation burning: a forage management system for longleaf pine-bluestem ranges. J. Range Manage. 17:322–326.

Dyksterhuis, E. J. 1949. Condition and management of range land based on quantitative ecology. J. Range Manage. 2:104–115.

Dyrness, C. T. 1973. Early stages of plant succession following logging and burning in the western Cascades of Oregon. Ecol. 54:57–69.

Dyrness, C. T. 1967. Grass-legume mixtures for roadside soil stabilization. U.S.D.A. For. Serv. Res. Note P.N.W.-71, 19 p.

Eckert, R. E., Jr. 1979. Establishment of pine transplants in perennial grass stands with atrazine. Weed Sci. 27(3):253–257.

Eddleman, L., and A. McLean. 1969. Herbage — its production and use within the coniferous forest. *In:* Coniferous Forests of the Northern Rocky Mountains: 1968 Symp. Proc. Centre Nat. Res., Univ. Montana Foundation, Missoula. p. 179–196.

Edgerton, P. J. 1971. The effect of cattle and big game grazing on a ponderosa pine plantation. U.S.D.A. For. Serv. Res. Note PNW-172, 8 p.

Eis, S. 1981. Effect of vegetative competition on regeneration of white spruce. Can. J. For. Res. 11:1–8.

Eis, S. 1965. Development of white spruce and alpine fir seedlings on cut-over areas in the central interior of British Columbia. For. Chron. 41(4):419–431.

Eissenstat, D. M. 1980. Water competition and animal damage in a grass-seeded Douglas-fir plantation. M.S. Thesis, Univ. of Idaho, Moscow. 65 p.

Eissenstat, D. M., J. E. Mitchell, and W. W. Pope. 1982. Trampling damage by cattle on northern Idaho forest plantations. J. Range Manage. 35:715–716.

Elliott, C. R., and H. Baenziger. 1977. Creeping red fescue. Can. Dept. Agric. Pub. 1122, 19 p.

Epstein, E. 1972. Mineral Nutrition of Plants: Principles and Perspectives. John Wiley and Sons, New York. 412 p.

Evanko, A. B. 1953a. Forage species and planting season for reseeding cleared and abandoned ponderosa pine areas in northeastern Washington. U.S.D.A. For. Serv., Northern Rocky Mtn. For. Range Expt. Sta., Res. Note 119, 5 p.

Evanko, A. B. 1953b. Performance of several forage species on newly burned lodgepole pine sites. U.S.D.A. For. Serv., Northern Rocky Mtn. For. Range Expt. Sta., Res. Note 133, 7 p.

Ffolliott, P. F., and W. P. Clary. 1975. Differences in herbage relationships on sedimentary and igneous soils in Arizona ponderosa pine stands. Prog. Agric. Ariz. 27(3):6–7.

Ffolliott, P. F., R. E. Thill, W. P. Clary, and F. R. Larson. 1977a. Animal use of ponderosa pine forest openings. J. Wildl. Manage. 41:782–784.

Ffolliott, P. F., W. P. Clary, and F. R. Larson. 1977b. Effects of a prescribed fire in an Arizona ponderosa pine forest. U.S.D.A. For. Serv. Res. Note RM-336, 4 p.

Fisher, R. F. 1980. Allelopathy: a potential cause of regeneration failure. J. For. 78(6):346–350.

Fisher, R. F., R. A. Woods, and M. R. Glavicic. 1978. Allelopathic effects of goldenrod and aster on young sugar maple. Can. J. For. Res. 8(1):1–9.

Forest Research Council of B.C. 1983. The management and silviculture of lodgepole pine in B.C.: An interpretive review. B.C. Min. For., Occasional Paper No. 1, 64 p.

Fowells, H. A. 1965. Silvics of forest trees of the United States. U.S.D.A. For. Serv., Agric. Handbook No. 271.

Garman, E. H. 1957. The occurrence of spruce in the interior of British Columbia. Dept. of Lands and Forests, B.C. For. Serv. Tech. Publ. T.49. 31 p.

Garrison, G. A. 1960. Recovery of ponderosa pine range in eastern Oregon and eastern Washington by seventh year after logging. Proc. Soc. Amer. For. 1960:137–149.

Garrison, G. A., and R. S. Rummell. 1951. First-year effects of logging on ponderosa pine forest range lands of Oregon and Washington. J. For. 49:708–713.

Geist, J. M. 1976. Orchardgrass growth on nitrogen and sulfur fertilized volcanic ash. J. Range Manage. 29(5):415–418.

Gesshe, R. H., and P. D. Walton. 1981. Grazing animal preferences for cultivated forages in Canada. J. Range Manage. 34:42–45.

Gjertson, J. O. 1949. Practical guides for seeding grass on skid roads, trails and landings following logging on east-side forests of Washington and Oregon. U.S.D.A. For. Serv., Pacific N.W. For. and Range Expt. Sta., Res. Note 49, 5 p.

Glen, L. M. 1979. Drag scarification in British Columbia. Info. Serv. Br., B.C. Min. For., Victoria. 60 p.

Gordon, D. T. 1962. Growth response of east side pine poles to removal of low vegetation. U.S.D.A. For. Serv. Res. Note PSW–209, 3 p.

Grelen, H. E. 1978. Forest grazing in the south. J. Range Manage. 31(4):244–250.

Grelen, H. E. 1976. Responses of herbage, pines and hardwoods to early and delayed burning in a young slash pine plantation. J. Range Manage. 29(4):301–303.

Grelen, H. E., and H. G. Enghardt. 1973. Burning and thinning maintain forage in a longleaf pine plantation. J. For. 71:419–425.

Grelen, H. E., L. B. Whitaker, and R. E. Lohrey. 1972. Herbage response to precommercial thinning in direct-seeded slash pine. J. Range Manage. 25:435–437.

Hafenrichter, A. L., L. A. Mullen, and R. L. Brown. 1949. Grasses and legumes for soil conservation in the Pacific Northwest. U.S.D.A. Misc. Pub. 678, 56 p.

Hall, F. C. 1980. Taking an ecological approach to multiple use planning. *In:* Beef Cattle and Range Res., Ore. State Univ., Agric Expt. Sta. Spec. Rep. 583, p. 37–47.

Hall, F. C. 1978. Applicability of rangeland management concepts to forest range in the Pacific Northwest. Proc. Int. Range. Cong. 1:496–499.

Hall, F. C. 1977. Forested habitat types and their suitability for livestock grazing. *In:* Management of Forest and Range in Interior British Columbia Proceedings. B.C. Min. For., B.C. Min. Env., B.C. Min. Agric., B.C. Min. Rec. and Cons., Kamloops, p. 78–84.

Hall, F. C. 1976. Fire and vegetation in the Blue Mountains — implications for land managers. Proc. Tall Timbers Fire Ecol. Conf. 15:155–170.

Hall, F. C. 1975. Range management as a counterpart of forest management. *In:* B. Roche, Jr. (ed.), Range: Multiple Use Management, Coop. Exten. Serv., Wash. State Univ., Pullman. p. 49–63.

Hall, F. C. 1966. Ecology as a tool in multiple-use management on forested areas. Proc. Soc. Amer. For. 1966:224–228.

Hanson, G. F. 1974. Cattle and timber management in the conifer/pinegrass stands of British Columbia. B.S.F. Thesis, Univ. Brit. Columbia, Vancouver. 29 p.

Harper, J. A. 1969. Relations of elk to reforestation in the Pacific Northwest. *In:* Wildlife and Reforestation in the Pacific Northwest, H. C. Black (ed.), School For., Ore. State Univ., Corvallis. p. 67–71.

Heady, H. F. 1975. Rangeland Management. McGraw-Hill, New York. 460 p.

Heady, H. F. 1964. Palatability of herbage and animal preference. J. Range Manage. 17:76–82.

Hedrick, D. W. 1975. Grazing mixed conifer forest clearcuts in northeastern Oregon. Rangeman's J. 2(1):6–9.

Hedrick, D. W. 1958. Proper utilization — a problem in evaluating the physiological response of plants to grazing use: a review. J. Range Manage. 11:34–43.

Hedrick, D. W., B. R. Eller, J. A. B. McArthur, and R. D. Pettit. 1969. Steer grazing on mixed coniferous forest ranges in northeastern Oregon. J. Range Manage. 22:322–325.

Hedrick, D. W., and R. F. Keniston. 1966. Grazing and Douglas-fir growth in the Oregon white-oak type. J. For. 64:735–738.

Hedrick, D. W., R. F. Keniston, and J. A. B. McArthur. 1971. Livestock and big game grazing on plantations in northeastern Oregon. Soc. Range Manage. 24th Ann. Mtg., Reno, Nev. Abstr. of papers. 22 p.

Hedrick, D. W., J. A. Young, J. A. B. McArthur, and R. F. Keniston. 1968. Effects of forest and grazing practices on mixed coniferous forests of northeastern Oregon. Ore. State Univ., Corvallis. Agric. Expt. Sta. Tech. Bull. 103, 24 p.

Heerwagen, A. 1954. The effect of grazing use upon ponderosa pine reproduction in the Rocky Mountain area. Proc. Soc. Amer. For. 1954:206–207.

Helvey, J. D. and W. B. Fowler. 1979. Grass seeding and soil erosion in a steep, logged area in northeastern Oregon. U.S.D.A. For. Serv. Res. Note PNW-343, 11 p.

Herring, L. J. 1981. Superplugs: an early performance assessment. B.C. Min. For., Prince George Region, Regional Research Report No. 4a, 8 p.

Herring. L. J., and R. G. McMinn. 1980. Natural and advance regeneration of Engelmann spruce and subalpine fir compared 21 years after site treatment. For. Chron. 56(2):55–57.

Hess, E. A., R. D. Clark, and S. B. Slen. 1962. Shade pays off. Can. Cattlemen. 25(11):32–33.

Hess, J. P. 1983. Forestland grazing policy and practices on private timberlands in central Washington. Paper presented at Forestland Grazing Symp. Spokane, Wash. Feb. 23–25.

Hess, J. P. 1966. Management of livestock grazing on private timberland. Proc. Soc. Amer. For. 1966:231–232.

Hill, R. R. 1917. Effects of grazing upon western yellow pine reproduction in the national forests of Arizona and New Mexico. U.S.D.A. Bull. 580, 27 p.

Hobbs, E. E. 1954. A study of lodgepole pine and its effect on timber range management. B.Sc. Thesis, Univ. Brit. Columbia, Vancouver. 15 p.

Hodgkins, E. J. 1958. Effects of fire on undergrowth vegetation in upland southern pine forests. Ecol. 39:36–46.

Holechek, J. L., M. Vavra, and J. Skovlin. 1981. Diet quality and performance of cattle on forest and grassland range. J. Anim. Sci. 53(2):291–298.

Holechek, J. L., M. Vavra, J. Skovlin, and W. C. Krueger. 1982. Cattle diets in the Blue Mountains of Oregon. II. Forests. J. Range Manage. 35(2):239–242.

Hormay, A. L. 1940. The effects of logging on forage. Chronica Botanica 6:6–7.

Horsley, S. B. 1977. Allelopathic inhibition of black cherry by fern, grass, goldenrod and aster. Can. J. For. Res. 7:205–216.

Horton, J. S. 1950. Effect of weed competition upon survival of planted pine and chaparral seedlings. U.S.D.A. For. Serv., Calif. For. Range Expt. Sta., Res. Note 72, 6 p.

Howard, W. E. 1950. Wildlife depredations in broadcast seeding of burned brushlands. J. Range Manage. 3:291–298.

Hoyles, S. E. 1977. Forage species analysis on windrowed, burnt, scarified and untreated clearcuts in the lodgepole pine zone of the Kamloops Forest District. B.Sc. Thesis, Univ. Brit. Columbia, Vancouver. 37 p.

Hughes, H. D., M. E. Heath and D. S. Metcalfe (eds.). 1951. Forages. Iowa State College, Ames, Iowa. 724 p.

Illingworth, K., and J. W. C. Arlidge. 1960. Interim report on some forest site types in lodgepole pine and spruce-alpine fir stands. B.C. For. Serv. Res. Note No. 35.

Ingram, D. C. 1931. Vegetative changes and grazing use on Douglas-fir cut-over land. J. Agric. Res. 43(5):387–417.

Ingram, D. C. 1928. Grazing as a fire prevention measure for Douglas-fir cut-over land. J. For. 28:998–1005.

Jackman, R. E., and N. N. Stoneman. 1973. Roadside grassing — a post-logging practice for redwood forests. J. For. 71(2):90–92.

Jameson, D. A. 1968. Species interactions of growth inhibitors in native plants of northern Arizona. U.S.D.A. For. Serv. Res. Note RM-113.

Jameson, D. A. 1967. Relationship of tree overstory and herbaceous understory vegetation. J. Range Manage. 20:247–249.

Jameson, D. A. 1966. Pinyon-juniper litter reduces growth of blue grama. J. Range Manage. 19:214–217.

Johnson, D. R. 1961. The food habits of rodents on rangeland of southern Idaho. Ecol. 42:407–410.

Johnson, W. M., and A. C. Hull, Jr. 1949. Range forage species for seeding in ponderosa pine areas. U.S.D.A. For. Serv., Rocky Mtn. For. Range Expt. Sta., Res. Note 5, 3 p.

Kidd, W. J., and H. F. Haupt. 1968. Effects of seedbed treatment on grass establishment on logging road beds in central Idaho. U.S.D.A. For. Serv. Res. Paper INT-53, 9 p.

Kinsinger, F. E. 1979. Review of range trend and utilization methodology: use in rangeland ecosystem evaluation and management. *In:* K. M. W. Howes (ed.), Rangeland Ecosystem Evaluation and Management, Aust. Rangeland Soc., Perth, W. Aust. p. 137–172.

Klemmedson, J. O., R. D. Pieper, D. D. Dwyer, W. F. Mueggler, and M. J. Trlica. 1978. Research needs on western rangelands. J. Range Manage. 31(1):4–8.

Klock, G. O., A. R. Tiedemann, and W. Lopushinsky. 1975. Seeding recommendations for disturbed mountain slopes in north central Washington. U.S.D.A. For. Serv. Res. Note PNW-244, 8 p.

Kosco, B. H., and J. W. Bartolome. 1983. Effects of cattle and deer on regenerating mixed conifer clearcuts. J. Range Manage. 36:265–268.

Kosco, B. H., and J. W. Bartolome. 1981. Forest grazing: Past and future. J. Range Manage. 34(3):248–251.

Kothmann, M. M. (ed.) 1974. A glossary of terms used in range management, 2nd edition. Soc. Range Manage., Denver, Colo., 36 p.

Krajina, V. J. 1969. Ecology of forest trees in British Columbia. Ecology of Western North America 2(1):1–146.

Kranz, J. J., and R. L. Linder. 1973. Value of Black Hills forest communities to deer and cattle. J. Range Manage. 26:263–265.

Krueger, W. C. 1983. Cattle grazing in managed forests. Paper presented at Forestland Grazing Symp. Spokane, Wash. Feb. 23–25, 1983.

Krueger, W. C. 1981. How a forest affects a forage crop. Rangelands 3(2):70–71.

Krueger, W. C., and A. H. Winward. 1976. Effects of grazing and selective logging on a mixed coniferous forest. Proc. Ore. Aca. Sci. 1976:27–35.

Krueger, W. C., and A. H. Winward. 1974. Influence of cattle and big game grazing on understory structure of a Douglas-fir–ponderosa pine–Kentucky bluegrass community. J. Range Manage. 27(6):450–453.

Krueger, W. C., M. Vavra, and W. P. Wheeler. 1980. Plant succession as influenced by habitat type, grazing management and reseeding on a northeast Oregon clearcut. *In:* Research in Rangeland Management, Ore. State Univ., Agric. Expt. Sta. Spec. Rep. 586. p. 32–35.

Kruse, W. H. 1972. Effects of wildfire on elk and deer use of ponderosa pine forest. U.S.D.A. For. Serv. Res. Note RM-226, 4 p.

Lane, R. D., and A. L. McComb. 1948. Wilting and soil moisture depletion by tree seedlings and grass. J. For. 46:344–349.

Larson, M. M., and G. H. Schubert. 1969. Root competition between ponderosa pine seedlings and grass. U.S.D.A. Rocky Mtn. For. Range Expt. Sta. Res. Paper RM-54, 12 p.

Lay, D. W. 1957. Browse quality and the effects of prescribed burning in southern pine forests. J. For. 55:342–347.

Lay, D. W. 1956. Effects of prescribed burning on forage and mast production in southern pine forests. J. For. 54:582–584.

Lewis, B. P. 1965. Forage production and utilization in western Montana clearcuts. M. S. Thesis, Univ. Montana, Missoula. 101 p.

Lewis, C. E. 1980a. Simulated cattle injury to planted slash pine: girdling. J. Range Manage. 33:337–340.

Lewis, C. E. 1980b. Simulated cattle injury to planted slash pine: combinations of defoliation, browsing and trampling. J. Range Manage. 33:340–345.

Lewis, C. E. 1980c. Simulated cattle injury to planted slash pine: defoliation. J. Range Manage. 33:345–348.

Lewis, C. E. 1973. Integrating management of forest and range resources. *In:* Range Resources of the Southeastern United States. A.S.A. Special Pub. 21, p. 69–78.

Lewis, C. E., and T. J. Harshbarger. 1976. Shrub and herbaceous vegetation after 20 years of prescribed burning in the south Carolina coastal plain. J. Range Manage. 29:13–18.

Lewis, C. E., W. C. McCormick, and W. E. White. 1972. Cultivation, grazing, insects and disease affect yield of slash pine planted in sod. U.S.D.A. For. Serv. Res. Note SE-174, 8 p.

Lyon, L. J. 1976. Vegetal development on the Sleeping Child Burn in western Montana, 1961–1973. U.S.D.A. For. Serv. Res. Paper INT-184, 24 p.

McClure, N. R. 1958. Grass seedings on lodgepole pine burns in the northwest. J. Range Manage. 11:183–186.

McConnell, B. R., and J. G. Smith. 1971. Effect of ponderosa pine needle litter on grass seedling survival. U.S.D.A. For. Serv. Res. Note PNW-155, 6 p.

McConnell, B. R., and J. G. Smith. 1970. Response of understory vegetation to ponderosa pine thinning in eastern Washington. J. Range Manage. 23:208–212.

McConnell, B. R., and J. G. Smith. 1965. Understory response three years after thinning pine. J. Range Manage. 18:129–132.

MacDonald, M. A. 1952. Pine needle abortion in range beef cattle. J. Range Manage. 5:150–155.

McEwen, L. C., and D. R. Dietz. 1965. Shade effects on chemical composition of herbage in the Black Hills. J. Range Manage. 18:184–190.

McIlvain, E. H., and M. C. Shoop. 1971. Shade for improving cattle gains and rangeland use. J. Range Manage. 24:181–184.

McLean, A. 1979a. Grazing forests and clearcuts. Western Wildlands 5(4):34–35.

McLean, A. 1979b. Range plant communities. *In:* Range Management Handbook for British Columbia, A. McLean (ed.) Wayside Press, Vernon, B.C. p. 37–53.

McLean, A. 1972. Beef production on lodgepole pine-pinegrass range in the Cariboo Region of British Columbia. J. Range Manage. 25:10–11.

McLean, A. 1970. Plant communities of the Similkameen Valley, British Columbia, and their relationships to soils. Ecol. Monogr. 40:403–424.

McLean, A. 1969. Fire resistance of forest species as influenced by root systems. J. Range Manage. 22:120–122.

McLean, A. 1967a. Beef production on lodgepole pine-pinegrass range in southern British Columbia. J. Range Manage. 20:214–216.

McLean, A. 1967b. Germination of forest range species from southern British Columbia. J. Range Manage. 20(5):321–322.

McLean, A., and A. H. Bawtree. 1971. Seeding forest rangelands in British Columbia. Can. Dept. Agric. Pub. 1463, 14 p.

McLean, A., and M. B. Clark. 1980. Grass, trees, and cattle on clearcut-logged areas. J. Range Manage. 33:213–217.

McLean, A., and W. D. Holland. 1958. Vegetation zones and their relationship to the soils and climate of the upper Columbia Valley. Can. J. Plant Sci. 38:328–345.

McLean, A., and L. Marchand. 1968. Grassland ranges in the southern interior of British Columbia. Can. Dept. Agric. Publ. 1319, 28 p.

McLean, A., and E. W. Tisdale. 1960. Chemical composition of native forage plants in British Columbia in relation to grazing practices. Can. J. Plant Sci. 40:405–423.

McLean, A., and T. G. Willis. 1961. The range story of British Columbia. Agric. Inst. Rev., 4 p.

McLean, A., and W. Willms. 1977. Cattle diets and distribution on spring-fall and summer ranges near Kamloops, British Columbia. Can. J. Anim. Sci. 57:81–92.

McLean, A., S. Freyman, J. E. Miltmore, and D. M. Bowden. 1969. Evaluation of pinegrass as range forage. Can. J. Plant Sci. 49:351–359.

McLean, A., E. R. Smith, and W. L. Pringle. 1964. Handbook on grazing values of range plants of British Columbia. Can. Dept. Agric. Res. Sta. Pub., Kamloops, B.C.

McMinn, J. W. 1980. Total-forest concept in multi-resource management. J. For. 78:208–210.

Majak, W., D. E. Waldren, and A. McLean. 1977. Pine needle water extracts as potential abortive agents in gestating cow diets. J. Range Manage. 30(4):318–319.

Martin, J. H., W. H. Leonard, and D. L. Stamp. 1976. Principles of Field Crop Production, 3rd Edition. MacMillan, New York. 1118 p.

Miller, R. F., and W. C. Krueger. 1976. Cattle use on summer foothill rangelands in northeastern Oregon. J. Range Manage. 29:367–371.

Miller, R. F., W. C. Krueger, and M. Vavra. 1981. Deer and elk use on foothill rangelands in northeastern Oregon. J. Range Manage. 34(3):201–294.

Miltimore, J. E. (ed.). 1972. Interactions between cattle and wild ungulates in southern British Columbia. Proc. Informal Work Plan. Meeting, Can. Agric. Res. Sta., Kamloops, B.C. Sept. 28–29, 84 p.

Mitchell, J. E., D. M. Eissenstat, and A. J. Irby. 1982. Forest grazing — an opportunity for diplomacy. Rangelands 4(4):172–174.

Mitchell, W. K. 1982. The construction and rehabilitation of logging landings in the Cariboo Forest Region. B.C. Min. For., Cariboo For. Reg. Res. Sect., Res. Brief No. 20, 30 p.

Mitchell, W. R., and R. E. Green. 1981. Identification and interpretation of ecosystems of the Western Kamloops Forest Reigon, Volumes 1 and 2. Info. Serv. Br., B.C. Min. For., Victoria.

Moir, W. H. 1966. Influence of ponderosa pine on herbaceous vegetation. Ecol. 47(6):1045–1048.

Monfore, J. D. 1983. Livestock — A useful tool for vegetation control in ponderosa pine and lodgepole pine plantations. Paper presented at the Forestland Grazing Symp., Spokane, Wash. Feb. 23–25.

Morris, M. S. 1947. The grazing use of forest lands in the Northern Rocky Mountain region. Proc. Soc. Amer. For. 1947:303–311.

Moss, A. 1977. Economics of post-logging treatments and resource use options. *In:* Management of Forest and Range in Interior British Columbia. B.C. Min. For., Kamloops, June 8–9, p. 86–96.

Mueller-Dombois, D. 1964. Effect of depth to water table on height growth of tree seedlings in a greenhouse. For. Sci. 10:306–316.

Newton, M., and W. S. Overton. 1973. Direct and indirect effects of atrazine, 2,4-D and dalapon mixtures on conifers. Weed Sci. 21:269–275.

Noble, D. L. 1979. Roots of lodgepole pine seedlings reach depth of only 3 to 4 inches their first season. U.S.D.A. For. Serv. Res. Note RM-363, 3 p.

Noble, D. L. 1973. Engelmann spruce seedling roots reach depth of 3 to 4 inches their first season. U.S.D.A. For. Serv. Res. Note RM-241, 3 p.

Noble, D. L., and R. R. Alexander. 1977. Environmental factors affecting natural regeneration of Engelmann spruce in the central Rocky Mountains. For. Sci. 23(4):420–429.

Noble, D. L., and F. Ronco, Jr. 1978. Seedfall and establishment of Engelmann spruce and subalpine fir in clearcut openings in Colorado. U.S.D.A. For. Serv. Res. Paper RM-200, 12 p.

Noble, D. L., C. B. Edminster, and W. D. Shepperd. 1979. Effects of watering treatments on germination, survival and growth of ponderosa pine: A greenhouse study. U.S.D.A. For. Serv. Res. Note RM-369, 6 p.

Noble, D. L., C. B. Edminster, and W. D. Shepperd. 1978. Effects of watering treatments on germination, survival and growth of Rocky Mountain Douglas-fir: A greenhouse study. U.S.D.A. For. Serv. Res. Note RM-357, 6 p.

Nyberg, J. B. 1979. Seasonal effects of fire on ponderosa pine/bunchgrass range: Year 1. M.Sc. Essay, Univ. Brit. Columbia, Vancouver. 71 p.

O'Connell, M. W. 1983. Forestland grazing on Boise Cascade owned lands in northeast Washington. Paper presented at Forestland Grazing Symp., Spokane, Wash., Feb. 23–25.

Ogilvie, R. T. 1969. The mountain forest and alpine zones of Alberta. *In:* Vegetation, Soils and Wildlife, J. G. Nelson and M. J. Chambers (eds.), Methuen, Toronto. p. 25–44.

Orr, H. K. 1970. Runoff and erosion control by seeded and native vegetation on a forest burn: Black Hills, South Dakota. U.S.D.A. For. Serv. Res. Paper RM-60, 12 p.

Pase, C. P. 1958. Herbage production and composition under immature ponderosa pine stands in the Black Hills. J. Range Manage. 11:238–243.

Pase, C. P., and R. M. Hurd. 1958. Understory vegetation as related to basal area, crown cover and litter produced by immature ponderosa pine stands in the Black Hills. Proc. Soc. Amer. For. 1958:156–158.

Patton, D. R. 1976. Timber harvesting increases deer and elk use of a mixed conifer forest. U.S.D.A. For. Serv. Res. Note RM-329, 3 p.

Pearson, H. A. 1974. Utilization of a forest grassland in southern United States. Proc. Int. Grass. Cong. 12:409–415.

Pearson, H. A. 1973. Calculating grazing intensity for maximum profit on ponderosa pine range in northern Arizona. J. Range Manage. 26(4):277–278.

Pearson, H. A. 1968. Thinning, clearcutting and reseeding affect deer and elk use on ponderosa pine forest in Arizona. U.S.D.A. For. Serv. Res. Note RM-119, 4 p.

Pearson, H. A., and L. B. Whitaker. 1974. Year-long grazing of slash pine ranges: effects on herbage and browse. J. Range Manage. 27:195–197.

Pearson, H. A., and L. B. Whitaker. 1973. Returns from southern forest grazing. J. Range Manage. 26(2):85–87.

Pearson, H. A., J. R. Davis, and G. H. Schubert. 1972. Effects of wildfire on timber and forage production in Arizona. J. Range Manage. 25:250–253.

Pearson, H. A., L. B. Whitaker, and V. L. Duvall. 1971. Slash pine regeneration under regulated grazing. J. For. 69:744–746.

Pharis, R. L., C. F. Bentley, W. E. Smith, H. B. Stelfox, C. R. Elliott, and R. W. Peake (eds.). 1957. Hay and pasture crops for Alberta. Alta. Dept. Agric., Exten. Serv., Pub. No. 63., 20 p.

Pickford, G. D., and E. R. Jackman. 1944. Reseeding eastern Oregon summer ranges. Ore. State College, Corvallis. Agric. Expt. Sta. Circ. No. 159, 48 p.

Pimental, D., P. A. Oltenacu, M. C. Nesheim, J. Krummel, M. S. Allen, and S. Chick. 1980. The potential for grass-fed livestock: Resource constraints. Sci. 207:843–848.

Pitt, M. D. 1983. Range condition and trend assessment in British Columbia. (In press).

Pitt, M. D. 1982. East Kootenay Problem Analysis: The interactions among grass, trees, elk and cattle. B.C. Min. For., Res. Br., Victoria. 65 p.

Pojar, J., R. Trowbridge, and D. Coates. 1982. A guide to the classification and interpretation of the sub-boreal spruce zone, Prince Rupert Forest Region, British Columbia (Preliminary Draft). B.C. Min. For., Smithers.

Preest, D. 1977. Long-term growth response of Douglas-fir to weed control. N.Z. J. For. Sci. 7:329–332.

Pringle, W. L., and A. McLean. 1962. Seeding forest ranges in the dry belt of British Columbia. Can. Dept. Agric., Ottawa, Pub. No. 1147, 11 p.

Pumphrey, F. V. 1971. Grass species growth on a volcanic ash-derived soil cleared of forest. J. Range Manage. 24:200–203.

Rawsthorne, S., F. R. Minchin, R. J. Summerfield, C. Cookson, and J. Coombs. 1980. Carbon and nitrogen metabolism in legume root nodules. Phytochem. 19:341–355.

Regelin, W. L., and D. C. Wallmo. 1978. Duration of deer forage benefits after clearcut logging of subalpine forest in Colorado. U.S.D.A. For. Serv. Res. Note. RM-356, 4 p.

Reid, E. H. 1965. Forage production in ponderosa pine forests. Proc. Soc. Amer. For. 1965:61–64.

Reid, E. H. 1947. Forest grazing in the Pacific Northwest. Proc. Soc. Amer. For. 1947:296–303.

Reid, M. S. 1979. Range management. *In:* Range Management Handbook for British Columbia, A. McLean (ed.), Wayside Press, Vernon, B.C. p. 71–84.

Reynolds, H. G. 1966a. Use of a ponderosa pine forest in Arizona by deer, elk and cattle. U.S.D.A. For. Serv. Res. Note RM-63, 7 p.

Reynolds, H. G. 1966b. Slash cleanup in a ponderosa pine forest affects use by deer and cattle. U.S.D.A. For. Serv. Res. Note RM-64, 3 p.

Reynolds, H. G. 1966c. Use of openings in spruce-fir forests of Arizona by elk, deer and cattle. U.S.D.A. For. Serv. Res. Note RM-66.

Richmond, R. M. 1983. Problems and opportunities of forestland grazing in the Pacific Northwest. Paper presented at the Forestland Grazing Symposium, Spokane, Wash., Feb. 23, 1983.

Rietveld, W. J. 1975. Phytotoxic grass residues reduce germination and initial root growth of ponderosa pine. U.S.D.A. For. Serv. Res. Paper RM-153, 15 p.

Rindt, C. A. 1965. A silviculturist looks at grass and grazing effects on ponderosa pine. Proc. Soc. Am. For. 1965:69–70.

Riney, T. 1966. Improvement of range management on forest lands. Proc. Int. Grass. Cong. 10:813–817.

Risser, P. G. 1969. Competitive relationships among herbaceous grassland plants. Bot. Rev. 35:251–284.

Roath, L. R., and W. C. Krueger. 1982. Cattle grazing and behaviour on a forested range. J. Range Manage. 35(3):332–338.

Ross, B. A. 1977. Compatibility of cattle grazing with timber production on British Columbia's interior rangelands. B.S.F. Thesis, Univ. Brit. Columbia, Vancouver. 43 p.

Roy, D. F. 1953. Effects of ground cover and class of planting stock on survival of transplants in the eastside pine type of California. U.S.D.A. For. Serv., Calif. For. Range Expt. Sta., Res. Note 87, 6 p.

Rummell, R. S. 1951. Some effects of livestock grazing on ponderosa pine forest in central Washington. Ecol. 32:594–607.

Rummell, R. S., and C. E. Holscher. 1955. Seeding summer ranges in eastern Oregon and Washington. U.S.D.A. Farmer's Bull. No. 2091. 34 p.

Russell, E. W. 1973. Soil Conditions and Plant Growth, 10th Edition. Longman, New York. 849 p.

Sage, R. W., Jr., and W. C. Tierson. 1975. Establishing vegetative cover along logging roads: Techniques — costs — benefits. Northern Logger. 24(4):16–17, 33–34, 38.

Sassman, R. W. 1972. Economic returns from planting forage in national forests. J. For. 70(8):487–488.

Schimke, H. E., L. R. Green, and D. Heavilin. 1970. Perennial grasses reduce woody plant seedlings — on mixed conifer fuel break. U.S.D.A. For. Serv. Res. Note PSW-203.

Select Standing Committee on Agriculture. 1979. Rangelands of British Columbia. B.C. Legislative Assembly, Victoria, B.C. 304 p.

Severson, K. E., and C. E. Boldt. 1977. Options for Black Hills forest owners: timber, forage, or both. Rangeman's J. 4:13–15.

Shepperd, W. D., and D. L. Noble. 1976. Germination, survival and growth of lodgepole pine under simulated precipitation regimes: A greenhouse study. U.S.D.A. For. Serv. Res. Note RM-328, 4 p.

Sims, H. P., and D. Mueller-Dombois. 1968. Effect of grass competition and depth to water table on height growth of coniferous tree seedlings. Ecol. 49:597–603.

Skovlin, J. M. 1965. Improving cattle distribution on western mountain rangeland. U.S.D.A. Farmer's Bull. No. 2212, 14 p.

Skovlin, J. M., and R. W. Harris. 1970. Management of conifer woodland grazing resources for cattle, deer and elk. Proc. Int. Grass. Cong. 10:75–78.

Skovlin, J. M., P. J. Edgerton, and R. W. Harris. 1968. The influence of cattle management on deer and elk. N. Amer. Wildl. Nat. Res. Conf. Trans. 33:169–179.

Skovlin, J. M., R. W. Harris, G. S. Strickler, and G. A. Garrison. 1976. Effects of cattle grazing methods on ponderosa pine-bunchgrass range in the Pacific Northwest. U.S.D.A. For. Serv. Tech. Bull. No. 1531, 40 p.

Smalll, G. E. 1980. Seasonal effects of fire on ponderosa pine/bunchgrass range and Douglas-fir/pinegrass range. M.S. Essay, Wash. State Univ., Pullman. 83 p.

Smith, D. M. 1962. The Practice of Silviculture, 7th Edition. John Wiley and Sons, New York. 578 p.

Smith, J. H. G. 1955. Some factors affecting reproduction of Engelmann spruce and alpine fir. B.C. For. Serv. Tech. Publ. T43, 43 p.

Smith, R. B., and E. F. Wass. 1976. Soil disturbance, vegetative cover and regeneration on clearcuts in the Nelson Forest District, British Columbia. Fisheries and Env. Can., Can. For. Serv., Pacific For. Res. Centre, Victoria, B.C. Rep. No. BC-X-151, 37 p.

Smoliak, S., and A. Johnston. 1968. Germination and early growth of grasses at four root-zone temperatures. Can. J. Plant Sci. 48:119–127.

Smoliak, S., A. Johnston, and R. W. Lodge. 1981a. Management of crested wheatgrass pastures. Can. Dept. Agric. Pub. 1473, 19 p.

Smoliak, S., M. Bjorge, D. Penney, A. Harper, and J. S. Horricks. 1981b. Alberta Forage Manual. Alta. Agric., Agdex 120/20–4, Edmonton. 87 p.

Sparhawk, W. N. 1918. Effect of grazing upon western yellow pine reproduction in central Idaho. U.S.D.A. Bull. 738, 31 p.

Spurr, S. H., and B. V. Barnes. 1973. Forest Ecology, 2nd Edition. Ronald Press, New York. 571 p.

Squire, R. O. 1977. Interacting effects of grass competition, fertilizing and cultivation on the early growth of *Pinus radiata* D. Don. Aust. For. Res. 7:247–252.

Stapledon, R. G., and W. Davis. 1928. Sensible seed mixtures. Welsh Plant Breed. Sta. Bull., Ser. H. 8:150–162.

Stewart, W. H. 1980. History of forest grazing near Kamloops, B.C. *In:* M. D. Pitt (ed.) Grazing Systems Seminar Proceedings, Fac. Agric. Sci., Univ. Brit Columbia, Vancouver, p. 19–22.

Stewart, R. E., and T. Beebe. 1974. Survival of ponderosa pine seedlings following control of competing grasses. Proc. West. Soc. Weed Sci. 27:55–58.

Stoddart, L. A., A. D. Smith, and T. W. Box. 1975. Range Management, 3rd Edition. McGraw-Hill, New York. 532 p.

Strang, R. M., and A. M. Johnson. 1980. Preliminary results of prescribed burning trials in forested rangelands of southern B.C. Ann. Meet., Pac. N. W. Sect., Soc. Range Manage., Portland, Ore.

Strickler, G. S., and P. J. Edgerton. 1976. Emergent seedlings from coniferous litter and soil in eastern Oregon. Ecol. 57:801–807.

Strothman, R. O. 1972. Douglas-fir in northern California: effects of shade on germination, survival and growth. U.S.D.A. For. Serv. Res. Paper PSW-84, 10 p.

Sullivan, T. P., and D. S. Sullivan. 1982a. Incidence of barking damage by snowshoe hares and red squirrels in lodgepole pine stands in central British Columbia. Can. J. For. Res. (in press).

Sullivan, T. P., and D. S. Sullivan. 1982b. Influence of range seeding on rodent populations in the interior of British Columbia. J. Range Manage. (submitted).

Sutton, R. F. 1969. Silvics of white spruce. Can. Dept. Fisheries and Forestry, Forestry Branch Publ. No. 1250. 57 p.

Tackle, D. 1959. Silvics of lodgepole pine. U.S.D.A. For. Serv., Intermountain For. and Range Expt. Sta. Misc. Publ. No. 19, 24 p.

Tarrant, R. F. 1956. Effects of slash burning on some physical soil properties. For. Sci. 2(1):18–22.

Thompson, W. W., and F. R. Gartner. 1971. Native forage response to clearing of low quality ponderosa pine. J. Range Manage. 24:272–277.

Tisdale, E. W. 1950. Grazing of forest lands in interior British Columbia. J. For. 48(12):856–860.

Tisdale, E. W., and A. McLean. 1957. The Douglas-fir zone of southern British Columbia. Ecol. Monogr. 27:247–266.

Tisdale, E. W., A. McLean, and S. E. Clarke. 1954. Range resources and their management in British Columbia. J. Range Manage. 7(1):3–9.

Utzig, G., D. MacDonald, G. Still, M. Ketcheson, T. Braumandl, and A. Warner. 1983. Ecological classification for the Nelson Forest Region (3rd Approximation). B.C. Min. For., Nelson, B.C. 79 p.

Vavra, M. 1983. Managing grazing animal response to forestland vegetation. Paper presented at the Forestland Grazing Symp., Spokane, Wash. Feb. 23–25, 1983.

Vavra, M., W. C. Krueger, and W. P. Wheeler. 1980. Cattle grazing potential on clearcuts. *In:* Research in Rangeland Management, Ore. State Univ., Corvallis. Agric. Expt. Sta. Spec. Rep. 586. p. 35–37.

Vlamis, J., H. H. Biswell, and A. M. Schultz. 1955. Effects of prescribed burning on soil fertility in second growth ponderosa pine. J. For. 53:905–909.

Watkins, J. M. 1940. The growth habits and chemical composition of bromegrass, *Bromus inermis* Leyss, as affected by different environmental conditions. J. Amer. Soc. Agron. 32:527–538.

Watts, S. (ed.) 1983. Range management. *In:* Forestry Handbook, 4th Edition. For. Undergrad. Soc., Fac. For., Univ. Brit. Columbia, Vancouver. p. 73–84.

Weaver, H. 1974. Effects of fire on temperate forests: western United States. *In:* Fire and Ecosystems, T. T. Kozlowski and C. E. Ahlgren (ed.) Academic Press, New York. p. 279–319.

Weaver, H. 1967. Fire and its relationship to ponderosa pine. Proc. Annual Tall Timbers Fire Ecol. Conf. 6:127–149.

Weaver, H. 1958. Effects of burning on range and forage values in the ponderosa pine forest. Proc. Soc. Amer. For. 1957:212–215.

Weaver, H. 1951. Observed effects of prescribed burning on perennial grasses in the ponderosa pine forests. J. For. 49:267–271.

Weaver, H. 1947. Fire — nature's thinning agent in ponderosa pine stands. J. For. 45:437–444.

Wheeler, W. P., W. C. Krueger, and M. Vavra. 1980. The effect of grazing on survival and growth of trees planted in a northeast Oregon clearcut. *In:* Research in Rangeland Management, Ore. State Univ., Corvallis. Agric. Expt. Sta. Spec. Rep. 586. p. 28–31.

Whelan, E. F. 1974. Future of rangelands in Canada. J. Range Manage. 27:256–257.

White, L. D. 1977. Forage production in a five-year-old fertilized slash pine *(Pinus elliottii)* plantation. J. Range Manage. 30:131–134.

White, L. D. 1973. Native forage resources and their potential. *In:* Range Resources of the Southeastern U.S., R.S. Campbell and W. Keller (ed.) ASA Spec. Publ. No. 21, Madison, Wisc. p. 1–17.

Whittaker, R. H., and P. P. Feeny. 1971. Allelochemics: chemical interactions between species. Sci. 171:757–770.

Winston, D. A. 1974. Urea fertilizer toxic to young jack pine seedlings. Tree Planters' Notes 25:5–6.

Wikeem, B. M. 1983. Five year plan, Range Research Program (1983/84 — 1988/89). B.C. Min. For., Res. Br., Kamloops, B.C. 23 p.

Wikeem, B. M., and R. M. Strang. 1983. Prescribed burning on British Columbia rangelands: the state of the art. J. Range Manage. 36:3–8.

Willms, W., A. McLean, R. Tucker, and R. Ritcey. 1980. Deer and cattle diets on summer range in British Columbia. J. Range Manage. 33:55–59.

Wilson, D. B. 1969. Effects of seeding rate of orchardgrass on the balance of species in a herbage mixture. Can. J. Plant Sci. 49:783–789.

Wilson, T. I. 1949. Out of the ashes come the grasses. Soil Cons. 15:36–39.

Wolters, G. L. 1982. Longleaf and slash pine decreases herbage production and alters herbage composition. J. Range Manage. 35:761–763.

Wolters, G. L. 1973. Southern pine overstories influence herbage quality. J. Range Manage. 26:423–426.

Wolters, G. L., A. Martin, and H. A. Pearson. 1982. Forage response to overstory reduction on loblolly-shortleaf pine-hardwood forest range. J. Range Manage. 35(4):443–446.

Wood, B. 1972. Forest grazing. Ore. State Univ., Corvallis. Coop. Exten. Serv. Circ. 798, 11 p.

Woodhouse, W. W., and W. R. Griffith. 1973. Soil fertility and fertilization of forages. *In:* Forages, the Science of Grassland Agriculture, 3rd Edition, M. E. Heath, D. S. Metcalfe, and R. F. Barnes (ed.) Iowa State Univ. Press, Ames. p. 403–415.

Young, J. A., J. A. B. McArthur, and D. W. Hedrick. 1967a. Forage utilization in a mixed coniferous forest of northeastern Oregon. J. For. 65:391–393.

Young, J. A., D. W. Hedrick, and R. F. Keniston. 1967b. Forest cover and logging — herbage and browse production in the mixed coniferous forest of northeastern Oregon. J. For. 65:807–813.

APPENDIX 1. Common and Scientific Names of Recognized Commercial Tree Species of British Columbia

Alder,	Red	*Alnus rubra*
Balsam,	Alpine fir	*Abies lasiocarpa*
	Amabilis fir	*A. amabilis*
	Grand Fir	*A. grandis*
Birch,	Alaska paper	*Betula neoalaskana*
	Common paper	*B. papyrifera*
	Western	*B. occidentalis*
Cedar,	Western red	*Thuja plicata*
Cypress,	Yellow cedar	*Chamaecyparis nootkatensis*
Fir,	Douglas-fir	*Pseudotsuga menziesii*
Hemlock,	Mountain	*Tsuga mertensiana*
	Western	*T. heterophylla*
Larch,	Alpine	*Larix lyallii*
	Tamarack	*L. laricina*
	Western	*L. occidentalis*
Maple,	Broadleaved	*Acer macrophyllum*
Pine,	Limber	*Pinus flexilis*
	Lodgepole	*P. contorta*
	Western white	*P. monticola*
	White bark	*P. albicaulis*
	Yellow (Ponderosa)	*P. ponderosa*
	Jack	*P. banksiana*
Poplar,	Trembling aspen	*Populus tremuloides*
	Cottonwood	*P. balsamifera*
Spruce,	Black	*Picea mariana*
	Engelmann	*P. engelmannii*
	Sitka	*P. sitchensis*
	White	*P. glauca*

Source: Mitchell and Green (1981); Appendix A.

APPENDIX 2. Common and Botanical Names of Plant Species Cited

GRASS AND GRASS-LIKE SPECIES

Bentgrass,	colonial	*Agrostis tenuis*
	highland	*A. tenuis oregonensis*
	redtop	*A. alba*
Bluegrass,	big	*Poa ampla*
	bulbous	*P. bulbosa*
	Canada	*P. compressa*
	Kentucky	*P. pratensis*
	mutton	*P. fendleriana*
	sandberg	*P. secunda*
Bluestem,	big	*Andropogon gerardii*
	broomsedge	*A. virginicus*
	fineleaf	*A. subtenuis*
	little	*A. scoparius*
	paintbrush	*A. ternarius*
	pinehill	*A. divergens*
	slender	*A. tener*
Bottlebrush,	squirreltail	*Sitanion hystrix*
Brome,	downy (cheatgrass)	*Bromus tectorum*
	mountain	*B. carinatus*
	smooth	*B. inermis*
Canarygrass,	reed	*Phalaris arundinacea*
Carpetgrass		*Axonopus affinis*
Cat-tail,	common	*Typha latifolia*
Danthonia		*Danthonia spp.*
Fescue,	alta	*Festuca altaica*
	Arizona	*F. arizonica*
	chewing's	*F. rubra* var. *commutata*
	creeping red	*F. rubra*
	hard	*F. ovina* var. *duriuscula*
	Idaho	*F. idahoensis*
	meadow	*F. elatior*
	rough	*F. scabrella*
	sheep	*F. ovina*
	tall	*F. elatior arundinacea*
	western	*F. occidentalis*
Foxtail,	meadow	*Alopecurus pratensis*
Grama,	blue	*Bouteloua gracilis*
Junegrass		*Koeleria cristata*
Lovegrass,	weeping	*Eragrostis curvula*
Muhly,	mountain	*Muhlenbergia montana*
Needlegrass,	green	*Stipa viridula*
	western	*S. occidentalis*
Oatgrass,	Parry's	*Danthonia parryi*
Oatgrass,	tall	*Arrhenatherum elatius*
Orchardgrass		*Dactylis glomerata*
Reedgrass,	bluejoint (Canada)	*Calamagrostis canadensis*
	pinegrass	*C. rubescens*
	slim stem	*C. neglecta*
Ricegrass,	roughleaf	*Oryzopsis asperifolia*
	large	*O. hymenoides*
Ryegrass,	cereal	*Secale cereale*
	Italian (annual)	*Lolium multiflorum*
	perennial	*L. perenne*
Sedge,	beaked	*Carex rostrata*
	elk	*C. geyeri*
	Northwest	*C. concinnoides*
	pennsylvania	*C. pennsylvanica*
	Ross	*C. rossii*

APPENDIX 2.—*Continued*

Timothy		*Phleum pratense*
Threeawn,	pineland	*Aristida stricta*
Trisetum,	tall	*Trisetum canescens*
Velvetgrass		*Holcus lanatus*
Wildrye,	altai	*Elymus angustus*
	blue	*E. glaucus*
	Russian	*E. junceus*
Wheatgrass,	beardlesss bluebunch	*Agropyron inerme*
	bluebunch	*A. spicatum*
	crested	*A. cristatum*
	intermediate	*A. intermedium*
	pubescent	*A. trichophorum*
	Siberian	*A. sibericum*
	slender	*A. trachycaulum*
	streambank	*A. riparium*
	tall	*A. elongatum*
Wood-reed,	nodding	*Cinna latifolia*

FORB AND FERN SPECIES

Adenocaulon,	American	*Adenocaulon bicolor*
Agoseris,	pale	*Agoseris glauca*
Alfalfa		*Medicago sativa*
Arnica,	heartleaf	*Arnica cordifolia*
Balsamroot		*Balsamorhiza sagittata*
Bladder-fern		*Cystopteris fragilis*
Bracken,	southern	*Pteridium aquilinum*
Burnet		*Sanguisorba minor*
Cinquefoil,	gland	*Potentilla glandulosa*
Clover,	alsike	*Trifolium hybridum*
	red	*T. pratense*
	rose	*T. hirtum*
	subterranean	*T. subterraneum*
	white	*T. repens*
Cudweed		*Gnaphalium* spp.
Dandelion		*Taraxacum officinale*
Dragonhead,	American	*Dracocephalum parviflorum*
Figwort,	lance-leaf	*Scrophularis lanceolata*
Fireweed		*Epilobium angustifolium*
Fleabane,		*Erigeron pumilis*
Geranium,	Carolina	*Geranium carolinianum*
Goatsbeard		*Tragopogon dubius*
Goldenrod		*Solidago* spp.
Hawksbeard,	western	*Crepis occidentalis*
Lettuce,	prickly	*Lactuca serriola*
Lupine,	tailcup	*Lupinus caudatus*
Meadowrue,	western	*Thalictrum occidentalis*
Milkvetch,	cicer	*Astragalus cicer*
	Canada	*A. canadensis*
	timber	*A. miser*
Mitrewort		*Mitella* spp.
Mullein		*Verbascum thapsus*
Onion,	Kellog	*Allium anceps*
Peavine,	flat	*Lathyrus sylvestris*
	creamy	*L. ochroleucus*
	Nevada	*L. nevadensis*
Poor-joe		*Diodia teres*
Sainfoin		*Onobrychis viciaefolia*
Sorrel,	sheep	*Rumex acetosella*
Stonecrop		*Sedum douglasii*
Strawberry		*Fragaria* spp.
Sunflower,	swamp	*Helianthus angustifolius*

APPENDIX 2.—*Continued*

Sweetclover,	white	*Melilotus alba*
	yellow	*M. officinalis*
Thistle,	bull	*Cirsium vulgare*
Trefoil,	big	*Lotus uliginosus*
	birdsfoot	*L. corniculatus*
Vetch,	crown	*Coronilla varis*
	hairy	*Vicia villosa*
	lana	*V. dasycarpa*
	perennial (bramble)	*V. tenuifolia*
Willowweed,	Watson's	*Epilobium watsonii*
Woollyweed		*Hieracium spp.*
Yarrow		*Achillea millefolium*

SHRUB AND TREE SPECIES

Alder,	mountain	*Alnus tenuifolia*
	sitka	*A. sinuata*
Ash,	green	*Fraxinus pennsylvanica*
Aspen,	trembling	*Populas tremuloides*
Bearberry		*Arctostaphylos uva-ursi*
Bitterbush		*Purshia tridentata*
Ceanothus,	fendler	*Ceanothus fendleri*
	snowbrush	*C. velutinus*
Cherry,	black	*Prunus serotina*
Currant,	squaw	*Ribes cereum*
	sticky	*R. viscosissimum*
Elderberry,	blue	*Sambucus cerulea*
Juniper,	alligator	*Juniperus deppeana*
Locust,	black	*Robinia pseudoacacia*
Mahonia,	creeping	*Mahonia repens*
Maple,	sugar	*Acer saccharum*
Ninebark		*Physocarpus malvaceus*
Oceanspray		*Holodiscus discolor*
Pachistima		*Pachistima myrsinites*
Pine,	coulter	*Pinus coulteri*
	Jeffrey	*P. jeffreyi*
	loblolly	*P. taeda*
	longleaf	*P. palustris*
	pinyon	*P. edulis*
	radiata	*P. radiata*
	red	*P. resinosa*
	shortleaf	*P. echinata*
	slash	*P. elliottii*
Raspberry,	red	*Rubus idaeus*
Rose		*Rosa spp.*
Serviceberry,	Saskatoon	*Amelanchier alnifolia*
Silverberry		*Elaeagnus commutata*
Snowberry		*Symphoricarpos albus*
Spiraea		*Spiraea spp.*
Thimbleberry		*Rubus parviflorus*
Twin-berry,	black	*Lonicera involucrata*
Twinflower		*Linnaea borealis*
Willow		*Salix spp.*

APPENDIX 3. Grass-Legume Mixes Recommended for Use on Forest Range in Southern British Columbia

NOTE: Seed mixes are revised frequently depending on past experience and availability of new varieties, so the mixes presented here may be altered in the future.

CARIBOO FOREST REGION

(Source: George Leroux, Range Coordinator, personal communication)

1. Roads and Landings Dry Mix, 1982
   - — forage and erosion control; not compatible with planted tree stock
   - — SBSa, SBSb, IDFa, IDFb, PPBGc, PPBGd, PPBGe

   Grasses

   Canada bluegrass
   Creeping red fescue
   Tall fescue
   Timothy
   Big bluegrass

   Legumes

   White clover
   Alfalfa
   Sweetclover

2. Roads and Landings Wet Mix, 1982
   - — forage and erosion control; not compatible with planted tree stock
   - — ESSFg, ESSFh, ICHb, ICHe, MSc, SBSb, SBSc

   Orchardgrass
   Canada bluegrass
   Creeping red fescue
   Timothy

   Alsike clover
   White clover
   Sweetclover
   Alfalfa

3. Cariboo Aerial Seeding Mix, 1982
   - — forage; not suitable for dry sites such IDFa, PPBGc, PPBGd, PPBGe

   Orchardgrass
   Timothy

   Alsike clover
   White clover
   Alfalfa

4. Cariboo Utility Mix, 1983
   - — forage and erosion control

   Orchardgrass
   Timothy
   Tall fescue
   Canada bluegrass

   Alskie clover

5. IDF Dry Mix, 1983
   - — forage

   Crested wheatgrass
   Bromegrass
   Orchardgrass
   Timothy

   Alsike clover
   White clover

6. Quesnel Forest Land Mix, 1982
   - — forage and erosion control; landings and skidtrails

   Orchardgrass
   Bromegrass
   Creeping red fescue
   Kentucky gluegrass
   Tall fescue

   Alsike clover
   White clover

7. IDF Forest Mix, 1981
   - — forage; primarily for moist sites; ICHe, IDFb, SBSb

   Orchardgrass
   Timothy
   Smooth brome
   Perennial ryegrass

   White clover
   Alsike clover

APPENDIX 3.—*Continued*

8. IDF Subzone Mix, 1981
   — forage; moist sites

   Orchardgrass
   Timothy
   Smooth brome
   Pubescent wheatgrass
   Slender wheatgrass
   Perennial ryegrass

   White clover
   Alsike clover

9. Sub-Boreal Spruce Mix, 1981
   — forage; ICHb, ICHe, IDFb, ESSFg, ESSFh, SBSa, SBSb, SBSc

   Orchardgrass
   Timothy
   Smooth brome

   Alsike clover
   White clover

10. F.D. 2 Roads and Landing Mix, 1982
    — forage and erosion control; IDFb, SBSb

    Orchardgrass
    Timothy
    Creeping red fescue
    Kentucky bluegrass

    Alsike clover
    White clover
    Sweetclover

11. Dry Range Mix, 1981
    — forage; IDFa, IDFb

    Smooth brome
    Orchardgrass
    Timothy
    Crested wheatgrass
    Intermediate wheatgrass
    Russian wildrye

    White clover
    Alfalfa

KAMLOOPS FOREST REGION

(Source: Mitchell and Green 1981)

12. Range Mix "A"
    — forage; IDFa, IDFb, PPBGa, PPBGd, PPBGf

Preferred	Alternate
Crested wheatgrass	Altai wildrye
Russian wildrye	Altai wildrye
Alfalfa	Sainfoin

13. Range Mix "B"
    — forage; IDFa, IDFb, IDFc, IDFd, MSc

    Perennial ryegrass
    Timothy
    Orchardgrass
    Alsike clover

    Smooth brome
    Slender wheatgrass
    Slender wheatgrass
    Red or white clover

14. Range Mix "C"
    — forage; IDFa, IDFd, ESSFe, MSb, MSc

    Perennial ryegrass
    Smooth brome
    Timothy
    Orchardgrass
    Alsike clover

15. Engineering Mix "D"
    — forage and erosion control; skidtrails, landings, logging disturbed areas
    — ESSFd, ESSFe, IDFa, IDFb, IDFc, IDFd, MSc

    Perennial ryegrass
    Orchardgrass
    Intermediate wheatgrass
    Timothy
    Alfalfa
    Red clover

APPENDIX 3.—*Continued*

16. Engineering Mix "F"
    - — forage and erosion control; skidtrails, landings
    - — IDFa, IDFb, IDFd, PPBGd

      Crested wheatgrass
      Pubescent wheatgrass
      Alfalfa
      Sweetclover

17. Engineering Mix "H"
    - — forage and erosion control; skidtrails, landings
    - — ESSFd, ESSFe, MSb, MSc

      Smooth brome
      Orchardgrass
      Timothy
      Alsike clover
      White clover

NELSON FOREST REGION

(Source: Utzig et al. 1983)

18. Dry Range Mix
    - — forage and erosion control on dry sites; IDF, PPBG

Grasses	**Legumes**
Intermediate wheatgrass	White sweetclover
Smooth brome	Alfalfa
Crested wheatgrass	

19. Dry Forest Mix
    - — forage and erosion control on moister sites; IDF, PPBG

Tall fescue	Alsike clover
Timothy	
Intermediate wheatgrass	
Orchardgrass	

20. Wet Forest Interim Grazing Mix
    - — forage; ICH, IDF, MS

Orchardgrass	Alsike clover
Timothy	

21. Spruce-Fir Interim Grazing Mix
    - — forage; ESSF, MS

Timothy	Alsike clover
Tall fescue	Red clover
Orchardgrass	
Intermediate wheatgrass	

Queen's Printer for British Columbia ©
Victoria, 1986